

1 A Reappraisal: The Natural History of Amniote Reproductive Modes In Light of Comparative
2 Evolutionary Genomics

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10 **Abstract**

11

12 There is a current lack of consensus on the ancestral parity mode, oviparity (egg-laying) and
13 viviparity (live-birth), of amniotes and squamates (snakes and lizards). How transitions between
14 parity modes occur at the genomic level has primary importance on how science conceptualizes
15 the origin of amniotes, and highly variable parity modes in Squamata. Within the context of
16 interdisciplinary literature—medical, poultry science, reproductive biology, and evolutionary
17 biology—I review the genomics and physiology of five broad processes (Main Five) expected to
18 change during transitions between parity modes: eggshell formation, embryonic retention,
19 placentation, calcium transport, and maternal-fetal immune dynamics. Throughout, I offer
20 alternative perspectives and testable hypotheses regarding proximate causes of parity mode
21 evolution in amniotes and squamates. Should viviparity have evolved early in the history of
22 Lepidosauria, I offer the basal cap hypothesis as a proximate explanation. The framework of this
23 hypothesis can be extended to amniotes to infer their ancestral state. Medawar’s paradigm
24 contextualizes embryos as analogous to allografts. However, an abundance of research across
25 mammals, birds, and reptiles demonstrates that the maternal immune response to
26 gestation/gravidity cannot be explained by immunosuppression, inertness, evasion, or
27 immunological barriers. However, a rare example of a species with an apparently inert response
28 to oviparous gravidity is *Lampropholis guichenoti*, an oviparous skink that differentially
29 expresses zero genes during gravidity—making it a reasonable model for the original amniote
30 egg. Overall, this review grounds itself in the historical literature while offering a modern
31 perspective on a subject that has fascinated scientists for centuries—the origin of amniotes.
32 Based on the cumulative evidence across the Main Five, I provide a mechanism through which

33 squamates may reverse back to oviparity; and make predictions on the directionality of
34 transitions in three reproductively bimodal species. I encourage the scientific community to
35 utilize this manuscript as a resource in comparative genomics studies, embrace the complexity of
36 the system, and thoughtfully consider the framework proposed.

37 *Key Words:* reproductive mode, parity modes, oviparity, squamates, eggshell deposition,
38 embryonic retention, embryonic calcium transport, maternal-fetal interface, comparative
39 evolutionary physiology.

40

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98 **I. Introduction**

99

100 A reappraisal is needed for the conceptual framework used to research the evolution of
101 oviparity (egg-laying) and viviparity (live-birth) in amniotes (birds, non-avian reptiles, and
102 mammals). Squamates (snakes and lizards) are unique amongst amniotes because they have
103 highly variable parity modes (Figure 1). Beginning with the first phylogenetic analyses on the
104 subject, a warm-blooded scientific disagreement has persisted over the labile nature of
105 evolutionary transitions between parity modes (Blackburn, 1999, 2015; de Fraipont, Clobert &
106 Barbault, 1996; Griffith et al., 2015; Harrington & Reeder, 2017; Lee & Shine, 1998; Pyron,
107 2015; Pyron & Burbrink, 2014; Recknagel et al., 2018, 2021b). A growing number of
108 transcriptomic and genomic studies analyzing the molecular underpinnings of reproductive mode
109 evolution in squamates (e. g., Brandley et al. 2012; Cornetti et al. 2018; Gao et al. 2019; Griffith et al.
110 2016, 2017; Foster et al. 2020, 2022; Recknagel et al. 2021a; Yurchenko et al. 2020; Xie et al. 2022) and
111 recent advances on the ancestral state of amniotes and dinosaurs contribute to this discussion (Jiang et
112 al., 2023; Norell et al., 2020). It is prudent to acknowledge that the relative difficulty of changing
113 phenotypes cannot be determined from morphology alone or unidentified physiological
114 mechanisms. At least theoretically, any phenotypic change could be facilitated by simple
115 genomic changes (e.g., a single nucleotide polymorphism) or any combination of multi-omic
116 changes to any number of loci. As research begins to reveal the molecular networks involved
117 with parity mode evolution, it is important to avoid bias that could be introduced by assumptions
118 on the feasibility of transitions. Through synthesis of modern and historical research on amniote
119 reproduction, this review aims to provide greater context for hypotheses testing on ancestral
120 states of parity modes in amniotes and squamates.

121 The earliest estimates predicted that viviparity evolved independently between 90-100
122 times in squamates (Blackburn, 1982, 1985, 1992). These estimates assumed that oviparity was
123 the ancestral state and, based on the theoretical grounds of Dollo's law, that reversals back to
124 oviparity should be exceedingly rare (Blackburn, 1992; Fitch, 1970; Neill, 1964; Tinkle &
125 Gibbons, 1977). An intermediate phenotype of re-evolving an eggshell has been considered as
126 physiologically unviable, preventing reversals (Blackburn, 1995; Griffith et al., 2015). This was
127 demonstrated when experimentally induced extended egg retention in phrynosomatid lizards
128 resulted in adverse embryonic development attributed to impeded gas exchange imposed by the
129 eggshell (Mathies & Andrews, 1999, 2000; Parker & Andrews, 2006). However, this result may
130 be clade-specific.

131 Intermediate phenotypes as fitness valleys assumes 1) eggshells inherently impede gas-
132 exchange and 2) that an eggshell must re-evolve before a reversal back to oviparity is possible
133 (Griffith et al., 2015). Contrarily, eggshells are considered a component of the placenta in
134 viviparous Rough Earth Snakes, *Haldea striatula*, and in viviparous reproductively bimodal
135 European Common Lizards, *Zootoca vivipara* and Yellow-bellied Three-toed Skinks, *Saiphos*
136 *equalis* (Stewart, 2013). Additionally, *Saiphos equalis* is a reproductively bimodal skink that has
137 an oviparous population with incubation times as short as 5 days, thus embryos spend significant
138 time in utero with an eggshell (Smith et al., 2001). Another surprising example of eggshells
139 being compatible with full embryonic development includes a report of a captive tortoise that
140 retained viable eggs until the hatching stage (Kuchling & Hofmeyr, 2022).

141 Several studies predict early origins of viviparity in squamates (Jiang et al., 2023; Pyron
142 & Burbrink, 2014) and reversals back to oviparity (de Fraipont et al., 1996; Fenwick et al., 2011;
143 Harrington & Reeder, 2017; Lee & Shine, 1998; Pyron & Burbrink; Recknagel et al., 2018).

144 *Saiphos equalis* proved the possibility of reversals when a viviparous individual oviposited an
145 egg prior to birthing fully developed young within the same litter (Laird et al., 2019). The
146 unusual absence of an egg-tooth in oviparous Arabian Sand Boas, *Eryx jayakari* (Lynch &
147 Wagner, 2010; Staub & Emberton, 2002) serves as additional biological evidence of a reversal,
148 though this has been challenged (Griffith et al., 2015). Importantly, extended embryonic
149 retention, characteristic of oviparous squamates compared to birds, is viewed as compatible with
150 labile transitions (Jiang et al., 2023). Current expectations are that oviparity may re-evolve more
151 easily in squamate lineages that recently evolved viviparity and which have not lost specific
152 avian eggshell-matrix proteins (Laird et al., 2019; Xie et al., 2022).

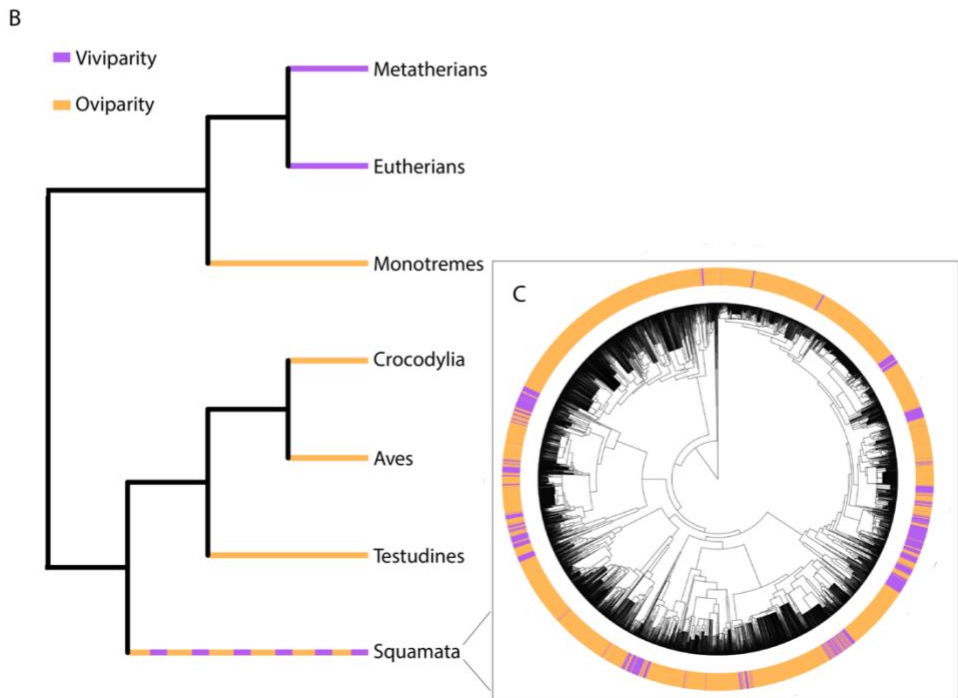
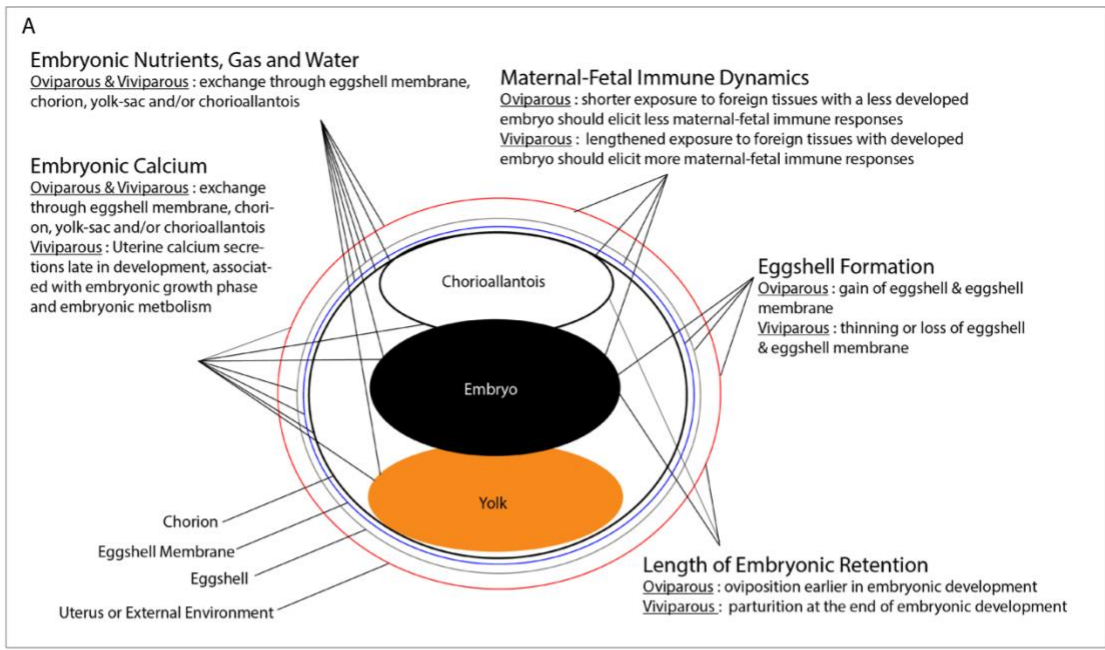
153 Discoveries of viviparity in ancient amniotes are numerous, dating back to the Early
154 Permian (Chuliver, Scanferla & Smith, 2022; Motani et al., 2014; Piñeiro et al., 2012; Jian et al.,
155 2023). A viviparous last common ancestor of amniotes may not be unreasonable. A compelling
156 example is the report that *Ikechosaurus sp.*, a basal archosauromorph, that reached an articulated
157 stage of embryonic development inside of a parchment shelled egg (Jiang et al., 2023). This and
158 the ancestral state reconstruction generated in the study bring support to the extended embryonic
159 retention model (EER) of amniotes origins (Jiang et al., 2023; Hubrecht, 1910). The EER model
160 postulates that amniote fetal membranes arose through pressure to support exposure to maternal-
161 fetal tissues during extended embryonic retention (see Laurin et al., 2005 for a summary of
162 earlier ancestral reconstructions of EER). As Romer (1957) phrased it “It was the egg which
163 came ashore first; the adult followed”. This is consistent with EER, which is compatible with
164 both oviparity and viviparity (Laurin, 2005; Mossman 1987). Throughout this review,
165 considering viviparity as the most extreme form of extended embryonic retention, I hope to
166 persuade readers to consider the EER model in a new light. I lay this out through a testable

167 hypothesis on the ancestral eggshell of amniotes and Lepidosaurs that can be extended to
168 amniotes (section III.3), a phylogenetic framework to infer ancestral states based on mechanisms
169 of maternal-embryonic calcium provisioning (section V.2), and evolutionary pathways that may
170 support transitions between parity modes (section VII.6 and VII.7).

171 It is sensible to equate the EER with pre-adaptations of the egg to land. Without
172 substantial amounts of water, converting yolk nutrients to somatic tissue is impossible
173 (Thompson & Speake, 2003). Water is the primary resource provisioned by the mother of
174 viviparous squamates and it is stored in extraembryonic membranes (Lourdais et al., 2015). For
175 example, improper water and gas exchange are associated with poor chorioallantoic blood flow
176 (Wootton et al., 1977). In oviparous *Saiphos equalis*, a species with extended embryonic
177 retention, the chorioallantois thickens to support embryonic growth in late development (Parker
178 et al., 2010). If the amniote egg evolved via the EER model, it may have prompted the origin of
179 extraembryonic membranes of amniotes to support embryonic water uptake despite the deficit of
180 water in utero compared to an aqueous environment. This translates to an egg washed ashore that
181 already evolved to withstand dryer environments.

182 Although models that restrict parity mode evolution to be unidirectional (from oviparity
183 to viviparity) are shown to be poor fits for squamates (Pyron & Burbrink; Recknagel et al.,
184 2021b), there is resistance to the proposition that viviparity originated early in Squamata (e.g.
185 Griffith et al., 2015). The most recent ancestral state reconstruction, built from biomineralization
186 and parity mode data across 80 extinct and extant amniotes using a single structured Markov
187 model, inferred viviparity with extended embryonic retention in the first amniotes and in the
188 most recent common ancestor of Lepidosaurs (squamates and sphenodontians) (Jiang et al.,
189 2023). However, maximum parsimony, and alternative maximum likelihood and Bayesian

190 reconstructions did not estimate viviparity in the most recent common ancestor of Lepidosaur
 191 (Jiang et al., 2023). A testable hypothesis regarding a molecular mechanism that may have
 192 supported a transition to viviparity at the base of squamates and extended embryonic retention at
 193 the base of amniotes will help conclude these decades long debates.



194

195 **Figure 1:** Schematic demonstrating (A) the anticipated processes that change during transitions
196 between oviparity and viviparity, and the organs associated with those changes. Lines from the
197 process to different organs indicate the organs expected to be involved with the evolutionary
198 shift between oviparous and viviparous phenotypes. (B) relationships between major amniote
199 clades and their associated reproductive mode, and (C) the variation of reproductive modes
200 across squamates. The squamate phylogeny is adapted from Pyron et al., (2016) and reproductive
201 modes of squamate species from Pyron & Burbrink (2014).

202

203 The ecological drivers of parity mode evolution are beyond the scope of this review.
204 However, it is generally proposed that viviparity increases protection from adverse
205 environmental conditions (Ma et al., 2018; Pincheira-Donoso et al., 2017), and a general trend
206 that supports this is the higher frequency of viviparous squamates, relative to oviparous,
207 observed at increasing distances from the equator. The cold-climate hypothesis suggests that
208 viviparity is an adaptation to cold climates, and this is generally accepted by the scientific
209 community (e.g. Ma et al., 2018; Zimin et al., 2022). Consistent with the cold-climate
210 hypothesis, a recent study that utilized 65 million years of global paleoclimate data, squamate
211 phylogeny and parity data for over 3,000 taxa showed that persistent, stable cold climates are
212 correlated with transitions to viviparity (Recknagel et al., 2021b). Less focus has been on the
213 adaptive nature of oviparity. Compared to viviparity, oviparity is associated with higher
214 fecundity and lessened maternal investment (Recknagel et al., 2019).

215 With a deep review of interdisciplinary literature across amniotes and associated
216 supplementary materials, I explore genomic and physiological features of gestation and
217 gravidity, including those that could be exploited to support labile shifts, ancestral viviparous

218 states in amniotes and squamates, and those that may facilitate or impede reversals. I propose the
219 framework of the basal cap hypothesis to help elucidate the ancestral parity modes of squamates
220 and amniotes. It details how squamates may have transitioned to viviparity (an extreme form of
221 extended embryonic retention) early in their evolutionary history. I advocate for using squamates
222 as a model to understand the ancestral state of the amniote egg. Future work should consider this
223 thoughtfully and embrace the complexity of the system. I hope this manuscript serves as a
224 foundation for further research on the evolutionary history of the amniote egg and reproductive
225 mode evolution.

226

227 *(1) Terminology*

228 I use the conventional definition of viviparity as retention of eggs until the stage when the
229 embryo is fully developed (Blackburn & Stewart, 2021; van Dyke et al., 2014). Oviparity is
230 defined by eggs that develop outside the mother. I use the terms gravidity and gestation to
231 describe the period of internal retention of the embryo in oviparous and viviparous taxa,
232 respectively. Vertebrate placentas are conventionally defined by apposition of maternal and fetal
233 tissues. It is accepted that all viviparous squamates have a chorioallantoic placenta under this
234 definition (Blackburn & Stewart, 2021; Stewart & Blackburn, 1988). The avian chorioallantoic
235 membrane and mammalian chorioallantoic placenta are homologous (Metcalf & Stock, 1993). I
236 sometimes refer to this organ as the chorioallantoic tissue to describe it for both parity modes.
237 Oviposition refers to the process and act of egg-laying, while parturition refers to the process and
238 act of giving birth to live-young. Parition refers to both oviposition and parturition (Blackburn,
239 1992; Smith, 1975).

240

241 *(1) Main five physiological changes of parity mode transitions*

242 Several physiological features are expected to change during transitions between
243 oviparity and viviparity (Figure 1). I break this down into five physiological features (hereafter
244 Main Five)—1) length of embryonic retention (Murphy & Thompson, 2011; Packard et al.,
245 1977)—only viviparous mothers retain the embryo for the entirety of development; 2) eggshell
246 formation (Heulin et al., 2005; Packard et al., 1977; van Dyke et al., 2014)—viviparous embryos
247 generally do not have an eggshell; 3) placental development for maternal-fetal exchange of
248 required water, gas and/or nutrients (Blackburn, 1992, 2015; Thompson et al., 2000; Thompson
249 & Speake, 2006); 4) embryonic calcium provisioning (Packard et al., 1985; Shadrix et al., 1994;
250 Thompson & Speake, 2006)—sources of embryonic calcium and timing of uterine calcium
251 secretions generally differs between oviparous and viviparous reproduction; 5) maternal-fetal
252 immune dynamics (e.g., Graham et al., 2011; Hendrawan et al., 2017; Foster et al., 2020)—
253 viviparous reproduction is associated with maternal and embryonic exposure to foreign tissues,
254 which is likely to require enhanced regulation of maternal-fetal immune systems.

255

256 **II. Length of Embryonic Retention**

257

258 Viviparous amniotes retain the embryo until it is fully developed, but oviparous amniotes
259 retain the embryo for a fraction of that time. Rather than using precocious hatching and
260 parturition (PH&P), like that of opossums and early viviparous mammals (Wagner et al., 2014),
261 squamates evolve viviparity through extended egg retention (García-Collazo et al., 2012; Shine,
262 1983). Thus, processes affecting the length of embryonic retention are expected to change to
263 support transitions between parity modes (van Dyke et al., 2014).

264

265(1) *Parturition & oviposition*

266 The genes and hormones involved with initiating and ending gestation may provide insights
267 into the tools squamates can co-opt to change the length of embryonic retention during parity
268 mode transitions. Parturition terminates embryonic retention. Parturition can be divided into four
269 parts (Terzidou, 2007; Vannuccini et al., 2016)—quiescence (Phase 0), activation (Phase 1),
270 stimulation (Phase 2) and involution (Phase 3). In eutherian mammals, several processes
271 contribute to the initiation and termination of gestation including inflammation (Challis et al.,
272 2009; Hansen et al., 2017), maternal recognition of pregnancy (MRP), mechanical stretch of
273 uterine tissues (Sooranna et al., 2004; Shynlova et al., 2008), and fluctuating concentrations of
274 corticotropin-releasing hormone, progesterone, and estrogen (Challis et al., 2000; Condon et al.,
275 2004; Shaw & Renfree, 2001).

276

277 (i) *Quiescence & sustained progesterone production in reproductive tissues*

278 Extended embryonic retention could be achieved by triggering mechanisms that extend
279 uterine quiescence, inactivity of the uterus. Inhibition of myometrial contractions through
280 sustained progesterone production supports quiescence across different viviparous amniotes
281 (Bazer, 1992; Casey & MacDonald, 1997; Fergusson & Bradshaw, 1991; Ilicic et al., 2017;
282 Murphy & Thompson, 2011; Putnam et al., 1991; Soloff et al., 2011). The corpus luteum (or
283 plurally called corpora lutea), a transient progesterone-producing organ, produces progesterone
284 during gestation. Extended lifespan of the corpus luteum likely aided the evolution of viviparity
285 in mammals (Amoroso, 1968; Callard et al., 1992; Stouffer & Hennebold, 2015). Thus, early
286 research on squamate viviparity also explored the influence of corpus luteum lifespan. The

287 lifespan of corpora lutea associates with oviparous egg retention and oviposition (Diaz, Alonso-
288 Gomez & Delgado, 1994; Fox & Guillette 1987; Jones & Guillette 1982). Eggshell formation in
289 oviparous Whiptail lizards, *Cnemidophorus uniparens*, is even disrupted by experimental
290 removal of corpora lutea (Cuellar, 1979). The lifespan of corpora lutea do not consistently
291 correlate with length of embryonic retention in viviparous squamates like it does in mammals
292 (Albergotti & Guillette, 2011; Callard et al., 1992).

293 Maternal recognition of pregnancy (MRP) refers to the early signaling of the embryo to
294 prevent luteolysis (Thatcher, Meyer, & Danet-Desnoyers, 1995), degradation of the corpus
295 luteum. Luteolysis occurs in the absence of pregnancy. MRP enables continued progesterone
296 production by the corpus luteum to support uterine quiescence during early gestation. An
297 independent evolution of MRP is reported for Macropodidae, a lineage of marsupial mammals
298 (Freyer, Zeller, & Renfree, 2003), and endometrial recognition of pregnancy is recognized in the
299 opossum (Griffith et al., 2019). MRP has not been explicitly studied in squamates. However,
300 MRP likely happens in squamates, given that corpora lutea do not get degraded in the earliest
301 stages of gravidity/gestation in oviparous or viviparous squamates (Callard et al., 1992;
302 Albergotti & Guillette, 2011).

303 Different genes are signaled by embryos for MRP across mammals. Human chorionic
304 gonadotropin hormone (hCG) establishes MRP (Ross, 1979; Behrman et al., 1993; Duncan,
305 McNeilly, & Illingworth, 1998; Duncan, 2000; Ticconi et al., 2007). In pigs, MRP is
306 hypothesized to be triggered by collaborative signaling of estradiol (E2) and prostaglandins
307 (PGs) (Geisert et al., 2023). Similarly, glycoproteins, estradiol and prostaglandin E2 (PGE2)
308 have been implicated in signaling MRP in horses (Klein & Troedsson, 2011; Klein, 2016). In
309 ruminants, embryonic signaling of IFN- τ establishes MRP (Bazer, 2013; Bazer, Spencer & Ott,

310 1997; Thatcher et al., 1995). During gestation in the uterus of viviparous African Ocellated
311 skinks, *Chalcides ocellatus*, four receptors for interferon alpha, beta, omega, and gamma are
312 differentially expressed but no expression of IFN- τ was detected compared to non-gestational
313 uterine tissue (Brandley et al., 2012). I was unable to find expression patterns of MRP signaling
314 homologs in other squamate reproductive tissues. Should MRP occur in squamates, it may be
315 signaled by genes that are clade-specific, like in mammals. This makes comparatively evaluating
316 the influence of MRP on the evolution of viviparity an interesting avenue for future research.

317 The evolution of viviparous extended embryonic retention may be sufficiently supported by
318 maintenance of chorioallantoic progesterone production coupled with eggshell loss (Griffith,
319 Brandley et al., 2017). This theory may be broadly applicable across amniotes given that the
320 most recent common ancestor of amniotes likely had a chorioallantois with an endocrine
321 function (Griffith, Brandley et al., 2017). Following death of the corpus luteum during gestation,
322 placental progesterone production supports extended embryonic retention in eutherian mammals
323 (Castracane & Goldzieher, 1986; Ellinwood et al., 1989; Nakajima et al., 1991; Rothchild, 2003;
324 Spencer & Bazer, 2004). Viviparous Italian Three-toed Skinks, *Chalcides chalcides*, shift to
325 chorioallantoic progesterone production following degradation of corpora lutea during gestation
326 (Guarino et al., 1998). The placenta of viviparous Southern Snow Skinks, *Carinascincus*
327 *microlepidotus*, produces minimal progesterone but has a strong capacity to convert
328 pregnenolone to progesterone (Girling & Jones, 2003). Whereas all genes involved with a known
329 biosynthesis pathway for progesterone production are expressed in the placenta of horses, *Equus*
330 *caballus*, only some of these genes were detected in the chorioallantois of chickens, *Gallus*
331 *gallus*, viviparous Southern Grass Skinks, *Pseudemoia entrecasteauxii*, and oviparous and
332 viviparous Southeastern Sliders, *Lerista bougainvillii* (Griffith, Brandley et al., 2017). Thus, if

333 chorioallantoic progesterone production has supported multiple origins of viviparity in amniotes,
334 it is not evidenced by a conserved ancestral gene expression pattern for the biosynthesis of
335 progesterone (Griffith, Brandley et al., 2017). Nonetheless, parity trait genes in a reproductively
336 bimodal lizard, *Zootoca vivipara*, are associated with progesterone-binding functions (Recknagel
337 et al., 2021a)—highlighting the role of progesterone in squamate reproduction.

338 Other female reproductive tissues in squamates express genes involved with progesterone
339 biosynthesis—StAR-related lipid transfer domain protein 3 (*StARD3*) and hydroxy-delta-5-
340 steroid dehydrogenase (*HSD3B1*). *STARD3* is significantly upregulated in the uterine tissue
341 during pregnancy in viviparous African Ocellated skinks, *Chalcides ocellatus*, along with
342 significant differential expression of seven paralogs (Brandley et al., 2012). While *StARD3* is
343 expressed during gestation in *Zootoca vivipara*, it is not significant differentially expressed
344 compared to oviparous counterparts; *HSD3B1*, on the other hand, is significantly upregulated
345 during mid-gestation (Recknagel et al., 2021a). Compared to non-gestational samples, *HSD3B1*
346 is significantly upregulated in the uterus during early and late gestation in viviparous individuals
347 of reproductively bimodal *Saiphos equalis* (Foster et al., 2020). Oviparous individuals from the
348 same species did not exhibit this expression pattern (Foster et al., 2020). Activity of *HSD3B1*
349 was detected in the mucosal epithelium of oviparous Eastern Garden Lizards, *Calotes versicolor*
350 (Kumari et al., 1992), and in the uterine glands of oviparous Keeled Indian Mabuya, *Eutropis*
351 *carinata* (Mundkur & Sarkar, 1982). Other genes involved with the biosynthesis of progesterone
352 (e.g., steroidogenic acute regulatory protein or cytochrome-P450-family-11-subfamily-A-
353 polypeptide-1) serve as further candidates for exploring the relationship between organ-specific
354 patterns of progesterone production and the evolution of extended embryonic retention in
355 viviparous squamates.

356 For progesterone to prevent myometrial contractions and support quiescence, there must be
357 progesterone receptors (PGRs) in the uterus (Mesiano et al., 2011; Young et al., 2011). In
358 humans, progesterone responsiveness is related to specific ratios of PGRs, *PR-A* and *PR-B*, in
359 myometrial cells (Young et al., 2011). Minimal research exists on PGR expression in squamate
360 reproductive tissues. One study found that in the uterus of the yolk-sac in viviparous Southern
361 Grass Skinks, *Pseudemoia entrecasteauxii*, one progesterone receptor, *PGRMC2*, is upregulated
362 compared to non-gestational uterine tissue (Griffith et al., 2016); Another progesterone receptor,
363 *PGR*, is downregulated in the uterus of the chorioallantoic placenta and yolk sac placenta
364 compared to non-gestational uterine tissue (Griffith et al., 2016). Downregulation of both *PGR*
365 and *PGRMC2* in the uterus during gestation was detected in viviparous *Chalcides ocellatus*
366 (Brandley et al., 2012). While *PGR* is differentially expressed at mid-gestation in viviparous
367 individuals compared to oviparous, *PGRMC1* and *PGRMC2* are not differentially expressed
368 (Recknagel et al., 2021a). However, admixture mapping revealed three SNPs most highly
369 associated with gestation length in *Zootoca vivipara* are located in close proximity to *PGRMC1*
370 (Recknagel et al, 2021a). Measuring expression of PGRs and their ratios in uteruses of
371 oviparous and viviparous squamates will help elucidate the receptors needed to support
372 progesterone responsiveness in squamate uteruses and their relationship to extended embryonic
373 retention.

374

375 (ii) *Activation & progesterone withdrawal*

376 The activation stage of parturition is marked by the withdrawal, or functional withdrawal, of
377 progesterone leading to an estrogen dominated response during the next state, stimulation
378 (Bakker, Pierce, & Myers, 2017; Fergusson & Bradshaw, 1991). Progesterone may withdraw in

379 response to environmental stimuli in reptiles during parturition (Shine & Guillette, 1988). In
380 mammals, activation is marked by increasing concentrations of corticotropin-releasing hormone
381 and contraction associated proteins (CAPs) including connexin-43, prostaglandins, oxytocin
382 receptors, prostanoid receptors and cell signaling proteins (Bakker et al., 2017; Ilicic et al., 2017;
383 Leadon et al., 1982; Pashen & Allen, 1979; Whittle et al., 2000). Pro-inflammatory cytokines
384 and chemokines, prostaglandin synthase-2 (*COX-2*, also referred to as *PTGS2*), and NF- κ B also
385 influence activation in mammals (Christiaens et al., 2008; Lappas et al., 2002; Lappas & Rice,
386 2007; Lindström & Bennett, 2005; Olson, 2003; Terzidou, 2007).

387 Some similar patterns are associated with oviposition in birds. In chickens, *Gallus gallus*,
388 prostaglandin F (PGF) concentrations increase in the hours leading up to oviposition (Takahashi
389 et al., 2004). Experimental injection of oxytocin and arginine vasotocin (AVT), similar
390 neurohypophyseal peptides, revealed that uterine tissues of chickens, *Gallus gallus*, maintain
391 responsiveness to oxytocin but are more sensitive toward arginine vasotocin (Ewy, 1970).
392 Murphy & Thompson (2011) provide a rather exhaustive list of resources on progesterone and
393 estrogen assays across oviparous and viviparous squamates. Future research should consider
394 exploring parallels between mechanisms of activation in mammals and squamates. Any process
395 that can trigger or stall activation should lead to extended embryonic retention.

396

397 (iii) *Stimulation & electrical gradients, inflammation, and hormonal regulation*

398 Mechanical stretch, electrical gradients, inflammatory processes, and hormonal regulation
399 contribute to stimulation, the phase when contractions, cervical ripening and dilation occur.
400 Stimulation involves contributions from maternal and fetal tissues. As early as 460 BC there was
401 uncertainty over the proportional influence of mother or fetus on the initiation of parturition.

402 Hippocrates proposed that the fetus initiates parturition by pushing its feet on the fundus of the
403 uterus. Although the reality is not so cartoonish, mechanical stretch of the uterus from the
404 growing embryo plays a role in parturition (Lefebvre et al., 1995; Tamizian & Arulkumaran,
405 2004; Wray et al., 2015).

406 Physical stretching of the uterus causes an influx of calcium and sodium, altering the action
407 potential and enabling contractions (Kao & McCullough, 1975). Calcium further activates
408 voltage gated calcium channels on myometrial cell membranes, enhancing the influx of calcium
409 ions, mediating the force and speed of myometrial contractility (Arrowsmith & Wray, 2014;
410 Wray et al., 2015). The influence of uterine overdistention on parition in birds and non-avian
411 reptiles has not yet been examined, to my knowledge. However, differentially expressed genes
412 functionally enriched the GO term for “voltage-gated calcium channel activity” in uterine tissues
413 during gravidity and gestation in *Saiphos equalis* (Foster et al., 2020). A uterine response to
414 overdistention is among the many possible explanations for this. It may be important to consider
415 the influence of uterine overdistention on squamate parity mode transitions, because should
416 bioelectrical responses to uterine overdistention be a common feature of vertebrate parturition,
417 lessened distention may be a hurdle to reverse back to oviparity. Uterine overdistention may
418 influence parturition by triggering an “inflammatory pulse” that activates further myometrial
419 contractility, which leads to preterm birth in primates (Adams Waldorf et al., 2015).

420 During parturition, there is an influx of uterine and embryonic pro-inflammatory genes and
421 immune cells (Adams Waldorf et al., 2015; Charpigny et al., 2003; Mesiano et al., 2002; Park et
422 al., 2005). Uterine contractions in humans involve actions of prostaglandins (PGs), oxytocin,
423 corticotropin-releasing hormone, cytokines, and neutrophils (Adams Waldorf et al., 2015; De

424 Rensis et al., 2012; Olson & Hertelendy, 1983; Park et al., 2005; Sykes et al., 2014; Terzidou,
425 2007).

426 The cycling concentrations of a neuropeptide, corticotropin-releasing hormone (CRH),
427 supports parturition in humans. This has been compared to a biological clock that is initiated at
428 early stages of gestation (Lockwood, 2004; McLean & Smith, 2001). Increased production of
429 CRH facilitates parturition by interacting with CRH receptors, CRH-R1 and CRH-R2, which are
430 suggested to promote myometrial relaxation or contractility, respectively (Hillhouse &
431 Grammatopoulos, 2001). Altered regulation, phenotype or function of hormones that function as
432 biological clocks, like CRH, may have a particularly strong influence on evolutionary changes to
433 length of embryonic retention, a trait inherently related to time.

434 Placental CRH production has only been identified in primates thus far (Challis et al., 2005;
435 Emanuel et al., 1994; Florio et al., 2002; Hillhouse & Grammatopoulos, 2001; Karteris et al.,
436 1998; Mendelson, 2009; Robinson et al., 1989). Placental CRH production may, therefore, be
437 unique to primates. However, the amino acid sequence of CRH is highly conserved in vertebrates
438 (Noy et al., 2017), indicating there is a possibility for shared function across diverse taxa. Like
439 CRH cycling in mammals, timely fluctuations of AVT stimulates uterine contractions, enables
440 oviposition in birds, turtles, and lizards (Ewy, 1970; Fergusson & Bradshaw, 1991; Guillette Jr &
441 Jones, 1980; Jones et al., 1987; Rzas, 1978; Wu et al., 2019).

442 Prostaglandin E₂ (PGE₂) and prostaglandin F_{2α} (PGF_{2α}) influence, respectively, uterine
443 contractions and cervical relaxation for partition across many amniotes including humans, *Homo*
444 *sapiens* (Terzidou, 2007), domestic pigs (De Rensis et al. 2012), domestic chickens (Hertelendy
445 et al., 1974; Olson et al., 1986), and Loggerhead Sea turtles (Guillette et al., 1991). Injections of
446 PGF_{2α} and PGE₂ induce parturition in viviparous Yarrow's Spiny lizards, *Sceloporus jarrovi*, and

447 Raukawa geckos, *Woodworthia maculatus* (Cree & Guillette, 1991; Guillette et al., 1992).
448 However, no injected dosages of PGF_{2α} or PGE₂ induced oviposition in oviparous Collard
449 lizards, *Crotaphytus collaris*, Eastern Fence lizards, *Sceloporus undulatus*, Six-lined
450 racerunners, *Aspidoscelis sexlineatus*, or Striped Plateau lizards, *Sceloporus virgatus* (Guillette et
451 al., 1991). It is interesting that injections of PGF_{2α} and PGE₂ induced parturition in viviparous
452 lizards but did not induce oviposition in oviparous lizards studied. Given this, it is plausible that
453 regulatory or functional changes to PGF_{2α} and/or PGE₂ in squamates could facilitate changes to
454 the length of embryonic retention to support transitions between reproductive modes. However,
455 induction of parturition with PGF_{2α} in viviparous *Woodworthia maculatus* only worked with
456 pre-treatment of β-adrenoceptor (Cree & Guillette, 1991).

457 PGF_{2α} decreases progesterone concentrations during stimulation (De Rensis et al., 2012). In
458 humans, biosynthesis of PGs is driven largely by the enzyme cyclooxygenase (*COX*)-2 rather
459 than *COX-1* (i.e., prostaglandin synthase-2 and -1) (Slater et al., 1995, 1999). This helps
460 maintain the decreased progesterone/estrogen ratio of stimulation. In ovariectomize viviparous
461 Garter snakes, *Thamnophis*, increased estrogen stimulated thickness of uterine epithelial cells
462 and glandular activity, whereas administration of progesterone had little influence on uterine
463 histology (Mead et al., 1981). Uterine pig models revealed that estrogen stimulates involuntary
464 contraction and relaxation (peristalsis) of the uterus (Mueller et al., 2006).

465 The softening of the cervix is important during the stimulation stage of parturition. A
466 hormone related to insulin, *relaxin*, promotes myometrial softening in humans, *Homo sapiens*,
467 domestic pigs, and turtles (Mercado-Simmen et al., 1982; Sorbera et al., 1988; Weiss &
468 Goldsmith, 2001). The cervix also gets softer by actions of PGE₂. PGE₂ activates pro-
469 inflammatory cytokines, interleukin (IL)-8 and tumor necrosis factor (TNF)-α, which activates

470 the collagenases and matrix metalloproteinases for cervical softening (Bakker et al., 2017). This
471 causes a positive feedback loop between IL-8 and PGE₂ synthesis (Denison et al., 1998;
472 Denison, Calder & Kelly, 1999; Terzidou, 2007; Li et al., 2010). Upregulated of IL-8 is also
473 promoted by the protein complex NF-κB during parturition in humans (Elliott, 2001). Similar
474 patterns were observed during parturition in mice and baboons (Mendelson & Condon, 2005;
475 Mendelson, 2009).

476 A few studies focus on the role of cytokines on squamate reproduction but not explicitly
477 during oviposition or parturition (Hendrawan et al., 2017; Paulesu et al., 1995, 2005, 2008).
478 Some studies detected expression of cytokines during late gestation (Foster et al., 2020; Gao et
479 al., 2019; Recknagel et al., 2021a). TNF-α related activity was only detected at this time in
480 viviparous Tussock Cool-skinks, *Pseudemoia entrecasteauxii*, which were found to
481 downregulate TNF-α induced proteins (*TNFAIP6* and *TNFAIP8L2*) in the ‘uterus of the
482 chorioallantoic placenta’ and *TNFAIP6*, *TNFAIP1*, and *TNFAIP2* in the ‘uterus of the yolk-sac
483 placenta’ compared to not gestational uterine tissues (Griffith et al., 2016). Activity of TNF-α in
484 reproductive tissues during gestation in viviparous Italian Three-toed skinks, *Chalcides*
485 *chalcides*, and reproductively bimodal European common lizards, *Zootoca vivipara*, was
486 associated with maternal-fetal immune dynamics (Paulesu et al., 1995, 2005, 2008; Hendrawan
487 et al., 2017).

488 Altered expression or phenotype of contractility agonists, oxytocin receptors and estrogen
489 receptors, and contractility antagonists, progesterone receptors and β-adrenergic receptors
490 (Ravanos et al., 2015) may also change the length of embryonic retention to support transitions
491 between parity modes. Differences in length of embryonic retention in oviparous and viviparous
492 agamas, *Phrynocephalus przewalskii* and *Phrynocephalus vlangalii*, appears to be driven by

493 regulatory differences of prostaglandins, *COX-2*, an AVT receptor (*MTR*), β -adrenergic receptors,
494 and estrogen receptors. During oviposition, *P. przewalskii*, exhibited the following: promotion of
495 contractions through downregulation of β -adrenergic receptor (*ADRB2*), and upregulation of
496 *COX-2* and prostaglandin, and absent (potentially lost) expression of two estrogen receptors
497 (*ESR1* and *ESR2*) and the AVT receptor, *MTR* (Gao et al., 2019). During the stage of gestation
498 corresponding to oviposition, viviparous sister-species, *P. vlangalii*, exhibited the following
499 alternate pattern: inhibition of contractions caused by upregulation of *ADRB2* and
500 downregulation of two estrogen receptors (*ESR1*, *ESR2*), *MTR*, *COX-2*, and prostaglandin (Gao
501 et al., 2019). Some viviparous squamates, *Saiphos equalis*, *Chalcides ocellatus*, and *Pseudemoia*
502 *entrecasteauxii*, share some of these expression patterns (*COX-2*, *MTR*, and *ADRB*, respectively)
503 thought to be involved with extended embryonic retention in viviparous *P. vlangalii* (Brandley et
504 al., 2012; Foster et al., 2020; Gao et al., 2019; Griffith et al., 2016); and *ADRB2* is upregulated at
505 mid-gestation in viviparous *Zootoca vivipara* compared to oviparous counterpart (Recknagel et
506 al., 2021a). Overexpressed genes in viviparous uterine tissues of *Zootoca vivipara* also
507 functionally enriched pathways for beta 1 and beta 2 adrenergic receptor signaling pathways
508 (Recknagel et al., 2021a). This study, which compared uterine expression profiles during
509 gestation across viviparous species of squamates, rodents, canines, ungulates, and humans,
510 concluded that shared regulatory networks are recruited to support viviparity (Reckangel et al.,
511 2021a).

512 Recently, in humans, the only Classical Major Histocompatibility Antigen (C-MHC)
513 expressed by trophoblasts (specialized placental cells) was associated with parturition when it
514 was discovered that HLA-C is significantly increased during laboring term and preterm placentas
515 compared to non-laboring placentas (Hackmon et al., 2017). The authors suggested a mechanism

516 where fetal HLA-C open conformers on the placenta provoke inflammation of maternal tissues,
517 leading to parturition (Hackmon et al., 2017). Expression of MHC alloantigens, foreign antigens
518 to the host, by fetal cells is also associated with parturition in cows and horses (Benedictusa,
519 Koets & Ruttena, 2015; Davies et al., 2004; Joosten et al., 1991; Rapacz-Leonard et al., 2018).
520 Around one month prior to parturition in cows, endometrial epithelium thins and eventually
521 disappears completely, putting the antigen-presenting trophoblasts (Adams et al., 2007) in
522 contact with maternal connective tissue of the endometrium (Podhalicz-Dzięgielewska et al.,
523 2000). Fetal MHC alloantigens are proposed to promote the loosening of maternal and fetal
524 tissues (Benedictusa et al., 2015). MHC molecules are expressed during gestation in some
525 squamates (Murphy, Thompson & Belov, 2009) but their role in oviposition or parturition has
526 not yet been considered to my knowledge. Identifying the presence or absence of MHC
527 alloantigens on embryonic tissues before and during partition across more diverse taxa may
528 reveal how ubiquitous the influence of embryonic MHC molecules is on this.

529 Involution (phase 3) occurs after the embryo(s) is released. In eutherian involution, the
530 placenta detaches, and the uterus shrinks. This is supported by actions of prostaglandins
531 (Husslein, 1984) and oxytocin (Terzidou, 2007). It seems unlikely for processes of involution to
532 be related to evolutionary changes to the length of embryonic retention.

533

534 (2) *Unique qualities of oviposition & parturition in Sauropsids*

535 The physiology of avian oviposition is dependent on a circadian schedule (Williams, 2012).
536 A general model of an “open period”, when eggs are laid are separated by “laying gaps”
537 (Williams, 2012). Chicken ovulation and oviposition cycles leave an 8-hour open period where
538 luteinizing hormone (LH) and progesterone surge, initiating ovulation and continuing the cycle.

539 At the extreme, the ancient murrelet, *Synthliboramphus antiquus*, oviposits a two-egg clutch on
540 seven-day intervals (Williams, 2012). Longer laying intervals have been associated with longer
541 intervals between initiation of yolk development (Astheimer & Grau, 1990). Differing from
542 birds, oviparous squamates retain eggs longer than the ovarian cycle (Tinkle & Gibbons, 1977).
543 This suggests that oviparous squamates may rely on different molecular mechanisms to support
544 oviposition than birds.

545 Non-avian reptiles are unique in that they are the only ectothermic amniotes. This makes
546 them uniquely reliant on temperature for embryonic retention and associated embryonic
547 signaling to indicate the stage of embryonic development. Additionally unique, gemales are the
548 heterogametic sex in several squamates, leading some research to suggest chromosome linkage
549 evolution may increase the speed of evolution in genes associated with gestation length
550 (Recknagel et al., 2021a). Admixture mapping, made possible by the natural hybridization of
551 oviparous and viviparous populations of *Zootoca vivipara*, revealed 439 candidate genes
552 associated with embryonic retention (Recknagel et al., 2021a). Eleven of these genes were also
553 associated with eggshell traits (Recknagel et al., 2021a)—underscoring the pleiotropic roles of
554 some genes putatively involved in squamate parity mode evolution.

555

556(3) *Pre-term birth & embryonic retention mechanisms*

557 The literature on pre-term birth may be a fruitful avenue of research to inform understanding
558 on the evolutionary genomics of embryonic retention length. Slower increases of CRH (Ellis et
559 al., 2002) and higher expression of Neurokinin B, for example, are associated with pre-term birth
560 in humans (Torricelli et al., 2007). Injections of RU486, a progesterone receptor (PGR)
561 antagonist, promoted pre-term labor in rhesus macaques but the progression of physiological

562 activity differed from normal parturition (Haluska et al., 1987). Examining homologs of genes
563 involved with human pre-term birth in squamates may provide further candidates for genes that
564 could impact the length of embryonic retention in squamates. Some evolutionary studies are
565 taking implications of pre-term birth into account. For example, a comparative evolutionary
566 transcriptomics study across therians, monotremes, squamates, and an amphibian recently
567 associated *HAND2* with preterm birth in Eutherian mammals (Marinić et al., 2021).

568 In humans, pregnancy loss from infection follows distorted ratios of immune factors at the
569 maternal-fetal interface (Arenas-Hernandez et al., 2016; Chaturvedi et al., 2015; Chattopadhyay
570 et al., 2010). Future research on the evolution of lengthened embryonic retention to support
571 viviparity may benefit from exploring ratios of immune cells in the uterus and embryonic tissues
572 during term and pre-term pregnancy in squamates. I direct researchers to the literature on the
573 reptile immune system and immune cell ratios at the maternal fetal interface during term and pre-
574 term mammalian pregnancy for further exploration (Yang et al., 2019; Zimmerman, 2010, 2020).

575

576(4) *Discussion & future directions—embryonic retention and parity mode evolution*

577 The physiological processes involved with the start of gestation (maternal recognition of
578 pregnancy) and the end of gestation (partition) in birds and mammals provide insights into the
579 genes and hormones squamates may co-opt to alter length of embryonic retention during
580 transitions between parity modes. Unsurprisingly, hormones like estrogen and progesterone, play
581 important roles in partition across amniotes. Further processes to be examined in squamates
582 include signaling of homologous genes for MRP, placental progesterone production, novel
583 pathways for biosynthesis of progesterone, the role of beta 1 and beta 2 adrenergic receptor
584 signaling pathways, fluctuating ratios of progesterone receptors, the lifespan of the corpus

585 luteum across a broader range of taxa, production and circulation of homologs for AVT and
586 CRH or other similarly structured genes, expression of fetal alloantigens and inflammatory
587 cytokines in utero, and the influence of uterine overdistention on contractions. Regarding
588 squamate parity mode transitions, the role of uterine overdistention in mammalian parturition
589 suggests a lack of uterine overdistention may be one hurdle for reversals back to oviparity.
590 Understanding the evolutionary physiology and genomics of embryonic retention in oviparous
591 and viviparous squamates will benefit from focused attention on reproductively bimodal species
592 (Whittington et al., 2022) and from genomics/physiological research across more taxa that vary
593 in reproductive modes.

594

595 **III. Eggshell Formation**

596

597 Oviparous amniotic embryos develop within an eggshell that is at least partially
598 mineralized, whereas viviparous embryos generally do not. Primarily, the eggshell serves as
599 physical protection and calcium reserve (Stewart & Ecy 2010; Stewart et al., 2009). The
600 eggshell matrix contains immune properties and pores that enable gas exchange and water uptake
601 (Packard et al., 1982). Evolutionary transitions between parity modes therefore requires changes
602 to the process of eggshell formation. The history of research on the evolutionary morphology of
603 the amniote egg is important for future comparative research (Blackburn & Stewart, 2021). Some
604 have suggested that the amniote eggshell originated multiple times (Aoki, 1993).

605 Birds have hard calcareous eggshells. Other than two lineages of geckos with hard shells,
606 oviparous squamates have parchment-shelled eggs with a thin layer of calcium deposits on the
607 outer surface of the shell membrane (Blackburn & Stewart, 2021; Choi et al., 2018).

608 Monotremata (egg-laying mammals) have an eggshell but far less has been documented about its
609 structure compared to other amniotes (Legendre et al., 2022). The structure and physiological
610 mechanisms involved with eggshell calcification are most well resolved in birds (Choi et al.,
611 2018; Francesch et al., 1997; Jonchère et al., 2010, 2012; Rose-Martel, Du, & Hincke, 2012).
612 Eggshell deposition in tuatara and squamates differs dramatically (Choi et al., 2018). Viviparous
613 squamates lack an eggshell, absorb the eggshell during gestation, or have a thin layer of calcium
614 deposits.

615 The earliest records of amniote eggshells have features characteristics of Archelosaur
616 eggshells, including the mammillary layer (Stein et al., 2019; Legendre et al., 2022). Recent
617 reconstructions are consistent with a thin eggshell in ancestral dinosaurs (Norell et al., 2020;
618 Stein et al., 2019). It is important to consider that the semi-rigid shells of Lepidosaur and
619 testudines are not homologous (Legendre et al., 2022); the microstructure of Archelosauria
620 (birds, crocodiles, turtles and dinosaurs) and Lepidosaur eggshells are remarkably different (Choi
621 et al., 2018); and recent reconstructions of the composition and ultrastructure of dinosaur
622 eggshells revealed that calcified hard eggshell of dinosaurs originated three times (Norell et al.,
623 2020). In the remainder of this section, I consider how structural, mineral,
624 genomic/transcriptomic, and proteomic information on amniote eggshells can inform scientific
625 understanding of the ancestral eggshell of amniotes and Lepidosaur.

626 The genetic drivers of eggshell formation are not resolved in squamates. Two oviparous
627 lizards, *Lerista bougainvillii* and *Lampropholis guichenoti*, differentially express either zero or
628 two genes, respectively, in utero in non-gravid vs gravid comparisons (Griffith et al., 2016).
629 However, this study only measured gene expression at one developmental stage, making it
630 difficult to infer if regulatory changes influence eggshell formation. Nonetheless, oviparous

631 *Saiphos equalis* and *Phrynocephalus przewalskii* have extensive differential expression during
632 gravidity (Foster et al., 2020; Gao et al 2019). It is interesting to see drastically different uterine
633 gene expression profiles associated with oviparity, given that shared genes are recruited to the
634 uterus to support viviparity across diverse amniotes (Recknagel et al., 2021a). Under the
635 assumption that conserved traits should be accompanied with more similar gene expression
636 profiles than convergent traits, uterine gene expression profiles in themselves currently reveal
637 more conserved regulatory networks in utero for squamate viviparity than oviparity.

638 Some genetically determined traits are known to be evolutionarily labile in squamates, like
639 venom and limb reduction (Camaiti et al., 2021; Sites et al., 2011). In *Saiphos equalis*, shell
640 characteristics of facultatively partitioned oviparous and viviparous embryos are similar, leading
641 authors to infer that both parity modes utilize the same machinery to produce egg coverings
642 (Laird et al., 2019). In this species, environmental influences on gestation length, rather than
643 genetic influences on eggshell thickness, may play a more dominant role in parity mode
644 evolution (Laird et al., 2019). In *Zootoca vivipara*, Recknagel et al. (2021a) identified 38
645 candidate genes associated with eggshell traits and concluded that the genetic architecture of
646 eggshell traits is simpler than that of gestation length.

647

648 (1) *Mineral composition of eggshells*

649 The different mineral compositions of eggshells across amniotes may provide insight into the
650 differing physiological conditions and evolutionary histories under which they are formed (Table
651 1). Taxa use a polymorph of calcium carbonate—calcite, aragonite or vaterite—to develop the
652 eggshell (Hincke et al., 2012). Amorphous calcium carbonate (ACC) is a transient non-
653 crystalline precursor phase of calcite and aragonite that is important for many calcification

654 processes in invertebrates (Hincke et al., 2012). It was recently shown to control avian eggshell
 655 mineralization (Rodríguez-Navarro et al., 2015).

656 In birds, the organic components of uterine fluid promote the formation of calcite
 657 (Hernández-Hernández, Gomez-Morales et al., 2008; Hernández-Hernández, Rodriguez, et al.,
 658 2008; Hernández-Hernández, Vidal et al., 2008). Most amniotes use this polymorph (Hernández-
 659 Hernández, Gomez-Morales et al., 2008; Hernández-Hernández, Rodriguez, et al., 2008;
 660 Legendre et al., 2022). However, turtle eggshells are predominately developed with aragonite
 661 (Choi et al., 2022; Mikhailov, 1997). The eggshell of most squamates consists of an inner fibrous
 662 protein layer overlain by calcium carbonate that can be a single layer or scattered crystals (Choi
 663 et al., 2018; Packard & DeMarco, 1991; Stewart et al., 2010).

664 There are differing accounts on the microstructure of monotreme eggshells, however
 665 conceptus coats include three layers including zona pellucida, mocooid coat and shell coat
 666 (Frankenberg & Renfree, 2018). Further studies are needed test for secondary homology.
 667 Monotreme shells are described as proteinaceous, permeable, and flexible (Hughes, 1984).
 668 Marsupials lack an eggshell but have an eggshell coat, similar to that of monotremes
 669 (Frankenberg & Renfree, 2018), that is secreted by the epithelial cells and endometrial glands
 670 early on in embryonic development prior to implantation (Roberts et al., 1994; Roberts & Breed,
 671 1996). Upon hatching of the shell coat and attachment of the embryo, a cooperative
 672 inflammatory response ensues (Stadtmauer et al., 2020a, 2020b).

673 **Table 1.** Amniote Eggshell Ultrastructures

Taxon	Eggshell ultrastructure
Testudoid	Radial aragonite with organic core at base
Crocodiloid	Tabular, arranged in wedges of calcite with no organic core
Squamate	Two types: <ul style="list-style-type: none"> • rigid-shelled eggs with well-developed crystalline layer (dibamid and gekkonid lizards). Stem-like crystals grow downward making for a rigid shell • flexible-shelled eggs with parchment-like shell of fibrils overlaid with little thin crystal caps or no crystalline material (other squamates)

Ornithoid (avian)	Calcite with a clear boundary between lower and upper parts. Mammillary layer defines the lower portion of the shell, with calcite crystals that radiate upwards
Monotreme	Distensible, permeable and highly proteinaceous

674 Note: Adapted from Choi et al., (2018); Frankenberg & Renfree, (2018); Hallman & Griebeler, (2015); Hincke et
675 al., (2012); Trauth & Fagerberg, (1984)

676

677

678 (2) *Uterine glands & the evolution of parity modes*

679 Eggshell formation occurs in the uterus where the uterine glands secrete precursors of the
680 eggshell (Girling, 2002; Guillette, Fox & Palmer, 1989; Jonchère et al., 2010; Nys et al., 2004;
681 Picariello et al., 1989; Stewart & Eca, 2010). Uterine glands are critical for gravidity/gestation
682 in both oviparous and viviparous amniotes (Braz et al., 2018; Burton et al., 2002; Cooke et al.,
683 2013). For example, in humans, uterine glands provide histiotrophic nutrition to the early
684 embryo (Burton et al., 2002). In reptiles, precursors for the proteinaceous eggshell membrane are
685 secreted by the uterine glands (Corso, Delitala & Carcupino, 2000; Heulin et al., 2005; Palmer et
686 al., 1993). Calcium secretion can also involve uterine epithelial cells (Herbert, Thompson &
687 Lindsay, 2006; Thompson et al., 2007). Uterine epithelium of the soft-shelled turtle, *Lissemys*
688 *punctata punctata*, and the eastern collard skink, *Chrotaphytus collaris* stain positive for calcium
689 (Guillette et al., 1989; Sarkar et al., 1995).

690 Viviparous squamates have an absent or reduced eggshell membrane to facilitate gas
691 exchange (Blackburn, 1993; Braz et al., 2018). Some squamates are encased in the thin
692 membrane through the entirety of development like the viviparous lizard, *Zootoca vivipara*
693 (Heulin, 1989). Others have the membrane only in the early stages of embryonic development
694 like in garter snakes *Thamnophis radix* and *T. sirtalis* (Blackburn & Lorenz, 2003). Calcium
695 deposits are detected on the outer surface of the membrane throughout development in other
696 viviparous lizards (Stewart et al., 2013).

697 Reduced number or size of eggshell glands leads to reduced eggshell membrane thickness in
698 viviparous squamates. In chickens, variation in size, spacing, and neutron density of eggshell
699 glands may also be important for eggshell structure (Guillette & Jones, 1985). In the
700 reproductively bimodal Yellow-bellied three toed skink, *Saiphos equalis*, the density of eggshell
701 glands plays a role in eggshell thickness (Stewart et al., 2010). In the reproductively bimodal
702 lizard, *Zootoca vivipara*, viviparous individuals have a uterine glandular layer that is less
703 developed during the stage of eggshell formation compared to oviparous individuals (Heulin et
704 al., 2005). Additionally, in *Lerista fragilis*, which lays eggs that hatch within just hours of
705 oviposition, the uterus contains very few mucosal glands (Guillette, 1992). In the fence lizard,
706 *Sceloporus a. aeneus*, the irregular surface of the eggshell was attributed to the irregular spacing
707 of shell glands (Guillette & Jones, 1985). In an oviparous gecko, *Hemidactylus turcicus*, their
708 eggshell glands have loosely packed secretory granules that produce a hard, calcareous shell
709 (Girling et al., 1998). In a comparison of oviparous and viviparous water snakes from the genus
710 *Helicops*, viviparous embryos have thinner shell membranes which associated with reduced size
711 of eggshell glands (Braz et al., 2018). In an oviparous gecko, *Saltuarius wyberba*, their secretory
712 granules are tightly packed, and their shell is soft and parchmentlike (Girling et al., 1998). In a
713 viviparous relative, *Hoplodactylus maculatus*, there are far fewer eggshell glands, and where
714 there are glands, the secretory granules are smaller and more electron dense (Girling, Cree &
715 Guillette, 1997; Girling, Cree & Guillette, 1998). Smaller eggshell gland size during or after
716 vitellogenesis is also found in other viviparous squamates compared to oviparous counterparts
717 (Braz et al., 2018; Gao et al., 2019; Heulin et al., 2005). To my knowledge, in monotremes the
718 relationship between eggshell thickness and shell gland size, density or compaction of secretory
719 granules has not been explored.

720 In the oviparous Przewalski's toadhead agama lizard, *Phrynocephalus przewalskii*, 148 genes
721 are highly expressed in the uterus during the stage of eggshell gland development (Gao et al.,
722 2019). Only three of these are highly expressed in *P. vlangalii*, a viviparous close relative at this
723 time, suggesting differences in oviparous and viviparous eggshell gland development requires
724 regulatory changes to dozens of genes (Gao et al., 2019). In the opossum, a marsupial,
725 proliferation of uterine glands is not induced by the conceptus (Griffith et al., 2019).

726

727 (3) *Evolutionary implications of the physiology of eggshell formation*

728 Presumably because of the influence it has on food production, the process of eggshell
729 formation has been studied most extensively in chickens (Hincke et al., 2012). The avian
730 eggshell is formed in a cell-free environment, and it is the fastest calcifying process known to
731 biology (Hincke et al., 2012; Rodríguez-Navarro et al., 2015). During eggshell formation in
732 birds, uterine fluid containing a supersaturation of ionized calcium and bicarbonate ions
733 surrounds the egg (Nys et al., 1991). Transport of calcium in the uterus correlates with plasma
734 membrane Ca^{2+} -ATPase (*PMCA*) activity and with concentrations of calbindin-D28K within
735 shell gland epithelial cells (Herbert et al., 2006; Wasserman et al., 1991). This leads to the
736 spontaneous precipitation of calcium carbonate into calcite (Hincke et al., 2012). In the
737 oviparous lizard, *Lampropholis guichenoti*, immunofluorescence microscopy revealed activity of
738 *PMCA* in the uterus at the time of eggshell calcification (Thompson et al., 2007).

739 Eggshell formation begins with the eggshell membrane. Two unciliated cell types in the
740 uterus contribute to eggshell membrane formation in a viviparous skink, *Chalcides ocellatus*
741 *tiligugu* (Corso et al., 2000). One secretes sulfated glycosaminoglycans to form the inner shell
742 membrane, and the other which secretes acidic glycoproteins to form the outer layers (Corso et

743 al., 2000). Simple alveolar glands in the lamina propria secrete collagen fibers (Corso et al.,
744 2000). Inhibition of fiber formation or cross-linking, typically caused by aminopropionitrile or a
745 copper deficiency, causes distorted formations of the eggshell membrane in birds (Arias et al.,
746 1997; Chowdhury & Davis, 1995; Hincke et al., 2012).

747 In characteristic Archelosaur eggshells (Choi et al., 2018; Legendre et al., 2022), organic
748 aggregates are deposited onto the shell membrane creating mammillary knobs, which are absent
749 in Lepidosaur shells (Choi et al., 2018). Mammillary knobs are a distinct layer between the outer
750 eggshell membrane and the calcified shell matrix layer (Hamilton, 1986). Part of the mammillary
751 knobs, called basal caps, are embedded into the outer eggshell membrane fibers (Tyler, 1965).
752 Mammillary knobs serve as regions of crystal initiation where ACC is deposited (Gautron et al.,
753 2021) and converted into calcite crystals with no intermediate phase (Rodríguez-Navarro et al.,
754 2015). Cones are formed that radiate in all upward directions, extending up to the shell matrix
755 layer (Tyler, 1965). Despite the direct relationship between mammillary knobs and calcium
756 carbonate crystallization (Rao et al., 2015), the protein comprising mammillary knobs remains
757 uncharacterized. A keratan sulfate (KS)-proteoglycan, “mammillan”, has been implicated in the
758 composition of mammillary knobs (Fernandez et al., 2001; Hincke et al., 2012). Any given
759 proteoglycan is a product of multiple coding genes and biosynthesis of KS-proteoglycans is non-
760 trivial (Cateron & Melrose, 2018; Funderburgh, 2002; Iozzo et al., 2015). However,
761 investigations into the keratan sulfate proteoglycan proposed as “mammillan” and identifying its
762 Properties that Facilitate Calcium Deposition (P-FCD) has far reaching implications given that
763 KS-proteoglycans are proving to be important players in neurological and cancer research
764 (Leiphprakpam et al., 2019). The role of homologs of “mammillan” in eggshell formation in
765 squamates may reveal more about the evolutionary history of the eggshell in amniotes.

766 Parsimony would suggest that all oviparous amniotes shared an ancestral process of
767 eggshell formation. In Archelosaurs, the process of eggshell formation relies on mammillary
768 knobs and upward growth of calcite, as described above. In Lepidosaur eggshells, which have
769 substantially less calcite growth, calcium is deposited on the surface of the eggshell membrane
770 and, in the case of gekkonids and the tuatara, crystal growth proceeds inward toward the center
771 (Choi et al., 2018). The strikingly divergent structure and directionality of eggshell formation
772 between Archelosauria and Lepidosauria suggests that the dissimilar processes of eggshell
773 formation are a result of genetic drift (e.g. Schiffman & Ralph, 2022), selection for specific
774 eggshell traits, or, in the case of an early origin of viviparity in Amniotes (Jiang et al., 2023)
775 and/or Lepidosaurians (Pyron & Burbrink, 2014), eggshells are a derived convergent trait.

776 Hypothetically, if a version of the avian eggshell was the microstructure for basal
777 Lepidosaurians, loss of mammillary knobs and their basal caps should have prevented calcium
778 deposition since mammillary knobs are the site at which calcium carbonate spontaneously
779 precipitates into calcite in Archelosaurs. Given that embryonic signaling supports at least two
780 main differences between oviparous and viviparous squamates—the timing of calcium secretions
781 and the length of embryonic retention (Griffith et al., 2015, 2017; Stewart & Ecy, 2010)—the
782 loss of mammillary knobs/basal caps may have supported an early origin of viviparity in
783 squamates. It would have theoretically facilitated 1) an early loss of the eggshell, 2) enhanced
784 contact between maternal and embryonic tissues and 3) enhanced signaling from the embryo to
785 support both altered timing of calcium secretions and hormonal signaling for extended
786 embryonic retention. This potential mechanism for an early origin of viviparity in squamates is
787 proposed here, for the first time, as the basal cap hypothesis. When mammillary knobs originated
788 is of paramount importance to the basal cap hypothesis, and inferences that can be gained from

789 applying it to the evolution of oviparity and viviparity in amniotes. If a version of the avian
790 eggshell was the ancestral microstructure of oviparous amniotes, the loss of basal caps could
791 result in a rapid loss of the eggshell and thus a relatively fast transition to viviparity or extended
792 embryonic retention.

793 Extending to the ancestral state of amniotes (e.g. Jiang et al., 2023; Laurin, 2005; Romero,
794 1957), absence of functional “mammillan” with P-FCD in squamates and mammals would be
795 consistent with a derived state of calcified eggshells in Archelosaurs. Absence of functional
796 “mammillan” with P-FCD exclusively in Lepidosauria would be consistent with the basal cap
797 hypothesis. Presence of functional “mammillan” with P-FCD across Amniota would be
798 consistent with the conventional understanding that the amniote egg evolved to prevent
799 desiccation and enable gas exchange following oviposition of eggs on land (Romero, 1957).
800 Overall, identifying the evolutionary trajectories of the biosynthetic pathway of “mammillan”
801 across amniotes is likely to create a better picture of the evolution of the amniote egg.

802 New recommendations for estimating ancestral microstructure of amniote eggshells have
803 recently been put forth, which abandons the traditional classification of hard/soft/semi-rigid
804 shells (Legendre et al., 2022). Including the structure of eggshell membranes in viviparous
805 squamates (e.g. Corso et al., 2000) would also improve phylogenetic reconstructions of the
806 amniote eggshell.

807 Several pieces of biological evidence lend themselves to an early origin of viviparity in
808 Lepidosauria and the basal cap hypothesis including—the lack of homology between the semi-
809 rigid shells of testudines and Lepidosauria (Legendre et al., 2022), the later stage of embryonic
810 development when eggs are commonly oviposited in squamates (Blackburn, 1995), and the more
811 predominant reliance on yolk calcium rather than eggshell calcium in squamates compared to

812 Archelosaurs (Packard, 1994; Stewart & Ecaý 2010). Viviparity in the most recent common
813 ancestor of Lepidosaurians may provide clear evolutionary insights on these phenomena.

814 Other features of eggshells are also worth consideration. In chickens, ovotransferrin is
815 present in the eggshell membrane and basal cap-layer (Gautron, Hincke, Panh leux et al., 2001).
816 Ovotransferrin promotes the development of elongated crystals (Gautron, Hincke, Panh leux et
817 al., 2001). The resulting shell matrix is made up of the crystal layer and cuticle (Hamilton, 1986).
818 On the inner portion of the avian eggshell, it is unclear what prevents growing crystalized cones
819 from extending into the inner membrane or the albumen. Collagen type X has been implicated
820 (Arias et al., 1993, 1997; Hincke et al., 2012). The role of collagen type X in creating a boundary
821 that prevents calcite from passing through the eggshell membrane could inform squamate
822 eggshells deposition (as discussed, they deposit calcium only on the outer surface, or crystals
823 grow inward). The only non-avian eggshell matrix protein, pelovaterin, was identified in the soft-
824 shell turtle (Lakshminarayanan et al., 2005).

825 Over 500 proteins are found in the chicken eggshell matrix (Mann, Ma ek, & Olsen, 2006;
826 Mik  ik et al., 2007, 2010). Ovocleidin-116 (*OC-116*), ovocalyxin-36 (*OCX-36* or *BPIFB4*),
827 ovocalyxin-21 (*OCX-21*), and ovocleidin-17 (*OC-17*) are important for avian eggshell formation
828 (Hern andez-Hern andez, Gomez-Morales et al., 2008; Jonch re et al., 2010; Tian et al., 2010).
829 *OC-116*, *OC-36*, *OCX-21*, and *OC-17* are some of the most differentially expressed genes during
830 eggshell calcification in chickens (Gautron et al., 2007; Hincke et al., 1999, 2012; Jonch re et al.,
831 2010). Ovocalyxin-21 may serve as a chaperone protein along with the protein endoplasmic
832 (ENPL) to facilitate proper folding of the avian eggshell matrix (Jonch re et al., 2010). In birds,
833 *OC-17* is concentrated in the inner mammillary cone layer, it interacts strongly with ACC, and it
834 is implicated in early stages of biomineralization of the eggshell (Gautron et al., 2021).

835 Originally considered avian-specific, several homologs of avian eggshell matrix proteins
836 have now been identified in non-avian reptiles and mammals (Le Roy et al., 2021). A recent
837 study found a significantly reduced number of intact avian eggshell matrix proteins in viviparous
838 squamates compared to oviparous squamates, a pattern that was especially apparent in snakes
839 (Xie et al., 2022). This study also found that *OC-17* was only absent in viviparous squamates but
840 was always present in the oviparous species in the dataset (Xie et al., 2022). Due to this, and the
841 central role of *OC-17* in avian eggshell formation in birds, they ascribe losing intact *OC17* with
842 the prevention of reversals back to oviparity (Xie et al., 2022). However, given that *OC-17* is
843 implicated in initiation of mineralization in the mammillary cone layer, which is absent in
844 squamates, the necessity of *OC-17* for squamates eggshell formation requires further
845 investigation. Other genes, like osteopontin (*OPN* or *SPPI*), also play a central role in
846 biomineralization of the avian eggshell and should be investigated in squamates.

847 *OCX-36* and other bactericidal/permeability-increasing (BPI) family B proteins (also called
848 *LPLUNCs*) are now thought to have a common origin in vertebrates with multiple duplication
849 events (Gautron et al., 2007; Tian et al., 2010). Orthologs of *OCX-36* are found in Archelosauria
850 and Monotremata (Le Roy et al., 2021). In birds, *OCX-36* plays a role in innate immune
851 responses and is found in high concentrations in the inner eggshell membrane (Gautron et al.,
852 2007, 2011; Tian et al., 2010).

853 *OC-116* is homologous to mammalian *MEPE*, which plays a role in bone and teeth
854 mineralization (Bardet et al., 2010a, 2010b). In birds, *OC-116* influences shell thickness, elastic
855 modulus, and egg shape (Le Roy et al., 2021). *OC-116* was identified in a crocodile, *Crocodylus*
856 *siamensis*, proteome (Le Roy et al., 2021; Mikšík et al., 2018). Synteny analysis across seven
857 turtle species and platypus (*Ornithorhynchus anatinus*) revealed absence of *MEPE/OC116* (Le

858 Roy et al., 2021). Other genes and lncRNAs are purported to be important for the quality of
859 eggshell formation in hens—*FGF14*, *COL25A1*, *GPX8*, and several members of the solute
860 carrier protein (*SLC*) gene family (Yang et al., 2020). Research into lncRNAs activity in
861 squamate reproductive tissues during embryonic development represents another valuable track
862 for research.

863 Various evolutionary genomics studies have revealed squamate-specific candidates for shell
864 formation (e.g. Recknagel et al., 2021a; Gao et al., 2020). Some of these candidates span the
865 major clades of amniotes. Seven of the genes expressed during eggshell gland development in
866 *Phrynocephalus przewalskii*—*HYPOU1*, *KCNMA1*, *P4HB*, *PRDX4*, *PTN*, *RRBP1* and
867 *TRAMI*—are purported to be important for eggshell calcification in chickens (Brionne et al.,
868 2014). Given this overlap across species that diverged over 300 million years ago (Shen et al.,
869 2011), these are excellent candidates for further exploration.

870 A functional genomics study harnessed hybridizations of oviparous and viviparous
871 individuals of *Zootoca vivipara* to reveal 17 SNPs and 38 genes associated with eggshell traits
872 (Recknagel et al., 2021a). These genes enriched terms related to cell communication and the
873 immune system, while differentially expressed gene during gravidity enriched pathways for
874 transforming growth factor (Recknagel et al., 2021a). The three loci with the strongest
875 association with eggshell traits mapped closely to *LG MN*, *LYPLA1*, and *CRTCI* (Recknagel et
876 al., 2021a). The association of these genes with eggshell traits is particularly interesting. *LG MN*,
877 for example, is involved with the cadherin pathway. Cadherins have an established role in
878 squamate reproduction. In squamates, previous literature discusses how cadherins influence
879 embryonic attachment in viviparous taxa (Wu et al., 2011). *LG MN* is also differentially
880 expressed across many viviparous squamates and mammals (Recknagel et al., 2021a). Thus,

881 *LGMN*, appears to support both oviparous and viviparous gestation in different ways. There are a
882 number of ways to approach exploring how *LGMN* may support both maternal-fetal
883 interconnectivity (viviparous individuals) and eggshell formation (oviparous individuals). Cell-
884 to-cell communication analysis using single cell data on uteruses of a reproductively bimodal
885 species would enable researchers to identify different interaction networks of *LGMN* and
886 associated cells in oviparous vs viviparous individuals.

887 During gravidity in *Saiphos equalis* two GO terms associated with calcium homeostasis are
888 enriched by the set of upregulated genes (Foster et al., 2020). However, most of these genes are
889 associated with regular cellular responses to calcium and even those associated with calcium
890 transport are upregulated in both early and late stages of gravidity (Foster et al., 2020). Their role
891 in eggshell formation in this uniquely labile species is therefore ambiguous.

892 In oviparous individuals of another reproductively bimodal skink, *Lerista bougainvillii*, only
893 two genes are significantly differentially expressed in the gravid uterine tissue compared to non-
894 gravid uterine tissue (Griffith et al., 2016). No genes are differentially expressed in the gravid
895 uterine tissue of the oviparous garden skink, *Lampropholis guichenoti*, compared to non-gravid
896 uterine tissue (Griffith et al., 2016). The genes involved in the shelling process in these species
897 may not involve changes in expression from the non-gravid state. The dissimilarity in uterine
898 gene expression profiles across lizards during gravidity suggests there may be multiple ways
899 oviparous squamates shell their eggs. Given the variation already observed, the eggshell
900 deposition in squamates should be considered in a phylogenetic context and under the different
901 evolutionary history inferred by ancestral state reconstructions (Harrington & Reeder, 2017;
902 Pyron & Burbrink, 2014). Supplementary table 1 compares candidate genes associated with
903 eggshell formation and shell gland development in squamates to that of birds.

904

905 (4) *Pleiotropy of genes and proteins involved with eggshell formation*

906 Substantial pleiotropy of genes involved with eggshell formation would imply that regardless
907 of parity mode, taxa have innately conserved toolkits that can be readily exploited to form an
908 eggshell for oviparous gestation. In addition to the candidate genes associated with both
909 gestation length and eggshell traits in *Zootoca vivipara* (Reckagel et al., 2021a), several genes
910 associated with eggshell deposition have pleiotropic effects within species or have different
911 effects in oviparous vs. viviparous amniotes. Osteopontin (*SPP1* or *OPN*) is found in bone and
912 kidneys, and transports calcium to other tissues in the body (Pines et al., 1995). It plays an
913 important role in calcium carbonate biomineralization of the avian eggshell (Gautron et al.,
914 2021). It is highly expressed in the chicken uterus during calcification (Jonchère et al., 2010) but
915 supports pregnancy recognition and implantation in sheep (Bazer et al., 2011). Improper
916 functioning of *SPP1* in the uterus leads to cracked and abnormal shells in birds (Arazi et al.,
917 2009; Hincke et al., 2008).

918 When expressed in the uterus, some bone morphogenic protein-coding genes (*BMPs*) aid
919 eggshell calcification (Jonchère et al., 2010). *BMPs* are part of the *TGF- β* superfamily and are
920 involved with the formation of new cartilage and bone, and with biomineralization in corals and
921 mollusks (Canalis et al., 2003; Lelong et al., 2000; Zoccola et al., 2009). Chordin (*CHRD*) is an
922 antagonist of the *BMP* pathway. *BMP*-binding endothelial regulatory protein (*BMPER*) and
923 *CHRD* are expressed in the chicken uterus during the stage of eggshell calcification (Jonchère et
924 al. 2010). Regulation of *BMPs* by *CHRD* is essential for early embryogenesis and adult
925 homoeostasis.

926 *BMPER* and seven *BMPs* are expressed during gestation in *Chalcides ocellatus*, a viviparous
927 skink (Brandley et al., 2012). Most of these are upregulated (Brandley et al. 2012). *BMP* genes
928 are expressed during both gravidity and non-gravidity in oviparous *Lerista bougainvillii* and
929 *Lampropholis guichenoti* (Griffith et al., 2016). *BMP2* is upregulated in oviparous late gestation
930 compared to viviparous late gestation in the reproductively bimodal lizard, *Saiphos equalis*
931 (Foster et al., 2020).

932 Differential expression of *BMPR1B* is associated with differences in eggshell quality in
933 chickens (Yang et al., 2020). Another study associated stage-specific high-expression of
934 *BMPR1B* with the stage corresponding to extended embryonic retention and placentation in
935 *Phrynocephalus vlangalii* (Gao et al., 2019). They identified a co-expression network of highly
936 expressed genes, including *BMPR1B*, that they associated with placentation (Gao et al., 2019).
937 *BMPR1B* also reaches significant levels of differential expression in uterine tissues of other
938 gestating viviparous lizards, *Chalcides ocellatus* and *Pseudemoia entrecasteauxii*, compared to
939 non-gestational uterine tissue (Brandley et al., 2012; Griffith et al., 2016). Receptors for *BMPs*
940 are also expressed in the uterus during gestation in other viviparous lizards, *Phrynocephalus*
941 *vlangalii* and *Pseudemoia entrecasteauxii* (Gao et al., 2019; Griffith et al., 2016). Perhaps
942 unsurprisingly, *BMPR1B* is also differentially expressed in the uterus of viviparous *Zootoca*
943 *vivipara* compared to oviparous individuals during gestation.

944 The potential role of these genes in squamate eggshell formation remains unclear. *BMPs*
945 influence on dorsal-ventral axis patterning during early embryogenesis and growth of skeletal
946 structures in post-natal tissues (Medeiros & Crump, 2012). It may be difficult to disentangle their
947 roles in embryonic development, placental development, and eggshell deposition. Future
948 research on them may inform scientific understanding of parity mode evolution.

949 *SLIT* genes are purported to be involved with folding the eggshell matrix in chickens
950 (Jonchère et al., 2010). The *SLIT2* gene functions across birds and mammals in diverse organs,
951 and encodes a protein that provides a structural framework for protein-protein interactions
952 (Jonchère et al., 2010; Marillat et al., 2002). In a functional genomics study, *SLIT2* was
953 identified as an important gene for eggshell traits in *Zootoca vivipara* (Recknagel et al., 2021a).
954 *SLIT2* is among the 50 most downregulated genes in the uterus during pregnancy in the
955 viviparous African ocellated skink, *Chalcides ocellatus*, compared to non-pregnancy (Brandley
956 et al., 2012). However, in the uterus of the yolk-sac placenta in the viviparous skink, *Pseudemoia*
957 *entrecasteauxii*, *SLIT2* is upregulated compared to non-reproductive uterine tissue (Griffith et al.,
958 2016). *SLIT3* is differentially expressed during the stage of placentation in the viviparous agama
959 lizard, *Phrynocephalus vlangalii* (Gao et al., 2019). *SLIT* genes also play a role in axonal
960 pathfinding and neuronal migration in rats (Marillat et al., 2002). *SLIT2* was associated with
961 reproduction in humans (Chen, Chu et al., 2015).

962 Podocalyxin (*PODXL*) is a sialoprotein associated with eggshell calcification in chickens
963 (Jonchère et al., 2010). In the viviparous Qinghai toad-headed agama lizard, *Phrynocephalus*
964 *vlangalii*, a weighted gene correlation network analysis associated *PODXL* with uterine
965 structural changes (Gao et al., 2019). The gene may play a role in placentation in these species
966 given that it was also differentially expressed in the uterus during the stage of placentation (Gao
967 et al., 2019). Interestingly, *PODXL* is downregulated in the uterus of the yolk-sac placenta in
968 another viviparous skink, *Pseudemoia entrecasteauxii* (Griffith et al., 2016). Based on its role in
969 chickens and *P. vlangalii*, *PODXL* is a good candidate for further research on the molecular
970 evolution of eggshell formation and placentation in squamates.

971

972 (5) *Eggshell formation termination*

973 When eggshell formation is terminated, the egg is still bathed in the supersaturated
974 calcium and bicarbonate ion fluid (Hincke et al., 2012). Some component(s) of the terminal
975 uterine fluid may prevent precipitation of calcium carbonate (Gautron, Hincke & Nys, 1997),
976 such as phosphate anions (Lin & Singer, 2005). The presence of phosphorous in the superficial
977 layers of the chicken shell suggest it may be a factor preventing the deposition of calcite crystals
978 in the terminal stage. Additionally, the high concentration of *OCX-32* in the outer eggshell and
979 cuticle, suggest that the gene may inhibit proteinaceous crystal growth in the terminal stage of
980 eggshell calcification (Gautron, Hincke, Mann et al., 2001). It is informative to viviparous
981 reproduction and consistent with the basal cap hypothesis that exposure to precursors of the
982 eggshell does not necessitate eggshell deposition. The influence of phosphate anions and *OCX-*
983 *32* on inhibition of calcium carbonate precipitation on the eggshell membrane of viviparous
984 squamate embryos has not been examined to my knowledge.

985

986 (6) *Rotating the egg for eggshell formation*

987 Oviparous amniotes rotate the egg for calcium formation and viviparous mammals rotate the
988 embryos for parturition. One hurdle to reversing back to oviparity may be re-evolving rotation of
989 the egg for shell formation early in gravidity (Griffith et al., 2015). Given the complex
990 musculature of the uterus across taxa, that allows for multidirectional force for parturition and
991 eggshell formation, it is difficult to determine the degree of difficulty for re-evolving appropriate
992 timing of egg-rotation. Cadherins and hormonal signaling support embryonic attachment (Wu et
993 al., 2011; Biazik et al., 2012), which can prevent rotation of the egg. Oviparous taxa lack
994 embryonic attachment, enabling the uterus to rotate the egg for eggshell formation. This rotation

995 does not happen until later in gestation for eutherian mammals when, for example, the embryo
996 detaches and cadherins become less concentrated (Wu et al., 2011). Perhaps a candidate gene for
997 studying this is, a cadherin *CDH5*, the only gene that is differentially expressed in all viviparous
998 squamates studied thus far studied (Recknagel et al., 2021a). Genes that enrich the GO term for
999 “voltage-gated calcium channel activity” are also useful candidates for investigating uterine
1000 rotation associated with eggshell formation because voltage-gated calcium channels effect the
1001 action potential of cells and can cause muscle contractions.

1002

1003 (7) *Discussion & future directions—eggshell formation and parity mode evolution*

1004 The process of eggshell formation is more resolved in birds compared to non-avian reptiles
1005 and monotremes (Choi et al., 2018; Frankenberg & Renfree 2018). I described some overlaps
1006 gleaned from the literature which prove as curious candidates for further research
1007 (Supplementary Table 1). Of particular interest are avian eggshell matrix proteins (Alföldi et al.,
1008 2011; Le Roy et al., 2021; Tian et al., 2010; Xie et al., 2022), genes with biomineralizations
1009 functions, candidate genes associated with eggshell traits in *Zootoca vivipara* (Recknagel et al.,
1010 2021a), and the homologs for avian eggshell matrix proteins identified in the *Anolis carolinensis*
1011 genome (Alföldi et al., 2011; Tian et al., 2010). Additionally, genes purported to be important for
1012 eggshell calcification in chickens associated with eggshell gland formation in an oviparous
1013 lizard, *Phrynocephalus przewalskii*, are relevant—*HYPOUI*, *KCNMA1*, *P4HB*, *PRDX4*, *PTN*,
1014 *RRBP1* and *TRAMI* (Brionne et al., 2014; Gao et al., 2019). Overlaps between the genes
1015 associated with gestation length and eggshell traits in *Zootoca vivipara* (Recknagel et al., 2021a)
1016 hint at genes that could potentially evolve to innately effect multiple traits relevant to parity
1017 mode transitions. The basal cap hypothesis also offers a simple evolutionary mechanism to

1018 investigate the evolutionary history of amniote parity mode evolution (see section III.3).
1019 Alternatives to the basal cap hypothesis are that dissimilar eggshells and eggshell deposition
1020 processes evolved through selective pressure, genetic drift, or both. Fortunately, the basal cap
1021 hypothesis can be utilized to ascertain the likelihood of this.

1022

1023 **IV. Placentation & Transport of Embryonic Water, Gas, and Nutrients**

1024

1025 The evolutionary pressures on fluid allocation, gas exchange and nutrient transport should
1026 differ between oviparous and viviparous taxa because their sources of all or some of these
1027 resources differ (Blackburn, 1992; Bonnet et al., 2001; Bonnet, Naulleau & Shine, 2017; van
1028 Dyke et al., 2014). In viviparity, maternal gas and water are accessed through the chorioallantois,
1029 which is especially important in the latter half of development (van Dyke et al., 2014; Carter,
1030 2012). Nutrients can be available from the yolk, maternal transfer, or both yolk and maternal
1031 transfer.

1032 While viviparity is associated with shared patterns of uterine gene expression during amniote
1033 gestation (Recknagel et al., 2021a), the same does not occur in viviparous amniote placentas
1034 (Foster et al., 2022). Instead, different genes that serve similar functions are recruited to the
1035 placenta across independent origins of viviparity (Foster et al., 2022). Additionally, where other
1036 amniotes can rely on the albumen for fluid allocation, squamates lack an albumen (Blackburn &
1037 Stewart, 2021). The eggshells of various squamates supports uptake of water from the
1038 environment (Blackburn & Stewart, 2021). The evolutionary implications of this have not been
1039 documented to my knowledge.

1040

1041 *(1) Anatomy & methods of water, gas & nutrient provisioning*

1042 The embryonic membranes regulate embryonic fluid transport, nutrient supply, respiration,
1043 immunity, and waste (Brace, 1997; Burton & Tullett, 1985; Ferner & Mess, 2011; Packard &
1044 Packard, 1980). Fluids are important for the developing embryo because they prevent desiccation
1045 and compression (Ferner & Mess, 2011; Packard & Packard, 1980). Over-abundance or under
1046 abundance of embryonic sac fluids leads to reproductive failure (Chamberlain et al., 1984;
1047 Fedakâr et al., 2016; Hadi, Hodson & Strickland, 1994; Mercer et al., 1984). Water is the
1048 predominant resource provisioned from the mother in most viviparous squamates (Lourdais et
1049 al., 2015).

1050 Oxygen flux in embryonic mammals is largely determined by oxygen-diffusing capacity of
1051 the placenta, the rates of blood flow in the umbilical and uterine arteries, and the oxygen
1052 capacities and affinities of fetal and maternal blood (Carter, 2009). Reptilian and mammalian
1053 blood vessels differ in basic characteristics such as capillary density, capillary surface, and
1054 oxygen diffusion gradients (Pough, 1980). Oviparous taxa regulate gas exchange through pores
1055 in their eggshells.

1056 Patterns of embryonic nutrient exchange can be broadly categorized into lecithotrophy,
1057 obtaining nutrients from the yolk, and placentrophy or matrotrophy, obtaining nutrients from the
1058 mother. Taxa belonging to Archelosauridae are lecithotrophic. The ancestral state of mammals
1059 was most likely oviparous matrotrophy that later evolved into viviparous matrotrophy in therians
1060 (Blackburn, 2005). The ancestral state of reptiles was likely lecithotrophy (Blackburn, 2005).
1061 Most viviparous squamates are lecithotrophic, some are lecithotrophic and matrotrophic, and a
1062 few have specializations for substantial matrotrophy (e.g. Blackburn, 2015a, Blackburn, 1985b;
1063 Stewart & Thompson, 1993; Thompson, Stewart et al., 1999; van Dyke et al., 2014). Even in

1064 lecithotrophic viviparous squamates some degree of organic or inorganic nutrients pass through
1065 the chorioallantoic placenta (Blackburn, 2005; Swain & Jones, 1997, 2000; Stewart & Eca, 2010; Thompson, Stewart et al., 1999; Thompson & Speake, 2002). Reversals may be most
1066 unlikely in lineages that have specialized placentas for substantial nutrient exchange because
1067 they would need to re-evolve lecithotrophy. Highly matrotrophic squamates are extremely rare
1068 (Blackburn, 2015a).

1070

1071 *(2) Evolutionary history of yolk-sac formation and yolk processing*

1072 Vitellogenesis is the process of yolk formation in the oocyte, providing the embryo with a
1073 valuable source of nutrients, primarily through the accumulation of precursor proteins to yolk,
1074 vitellogenins. Vitellogenin is produced in the liver, called hepatic vitellogenesis, and transported
1075 to the maturing ovum (Ho, 1987). Vitellogenins were lost in all mammals except monotremes
1076 (Brawand, Wahli & Kaessmann, 2008). They are a primary source of nutrition for other
1077 amniotes. Functionally similar to vitellogenin, caseins have persisted in all mammalian milks
1078 (Brawand et al., 2008). Active functioning of the yolk sac is restricted to the first trimester in
1079 placental mammals, and it is postulated to provide nutrients to the embryo (Kuzima et al., 2023).
1080 The detection of glycodelin in the yolk sac epithelium also supports this (Burton et al., 2002). In
1081 the yolk-sac of bats, dogs, and non-human primates the mesoderm derived layer is absorptive
1082 and may transfer substances from the exocoelomic cavity where the yolk sac is located (Enders
1083 et al., 1976; Freyer & Renfree, 2009; King & Wilson, 1983; Lee et al., 1983).

1084 The morphology of the yolk-sac and process of vitellogenesis differs between birds and non-
1085 avian reptiles. In birds, during the process of meroblastic cleavage, the zygote's cells divide
1086 while the yolk component does not. The yolk forms a large, fluid, non-cellularized mass

1087 surrounded by the extraembryonic yolk sac. The formation of the yolk-sac placenta in birds has
1088 the following pattern—first the bilaminar omphalopleure forms and then trilaminar
1089 omphalopleure; blood vessels move into folds of the extraembryonic endoderm, becoming
1090 stratified epithelium; the folds carrying the blood vessels reach the peripheral regions of the yolk
1091 only and the center of the yolk mass remains uncellularized (Starck, 2021). Intensive
1092 development of hemopoietic tissue surrounding the blood vessels during most of embryonic
1093 development, thus far, appears to be unique to birds (Starck, 2021). Compared to non-avian
1094 sauropsids, the unique pattern of yolk processing in birds facilitates faster embryonic
1095 development (Blackburn, 2021).

1096 The yolk sac characteristic of non-avian reptilian eggs serves as a model for the transition
1097 between the egg of anamniotes and amniotes (Blackburn, 2020). A series of recent papers,
1098 covering species of snakes, lizards, crocodiles, and turtles, indicate that these taxa utilize similar
1099 developmental pathways of yolk-sac formation and yolk processing that differs from birds
1100 (Blackburn, 2020, 2021; Blackburn et al., 2019; Elinson et al., 2014; Elinson & Stewart 2014;
1101 Stinnett et al., 2011). Across these taxa, a bilaminar/trilaminar omphalopleure overgrows the
1102 yolk mass, and the yolk mass gets invaded by proliferating endodermal cells that phagocytose
1103 the yolk material. These cells form clumps, progressively filling the yolk mass. Small blood
1104 vessels derived from yolk sac vasculature invade the yolk sac cavity and the endodermal cells
1105 arrange in monolayers around these vessels, forming “spaghetti bands” (Blackburn, 2021). The
1106 yolk sac of *Pantherophis guttatus* is one suitable model for studying the transition of the yolk-
1107 sac from anamniotes to amniotes (Elinson & Stewart, 2014; Elinson et al., 2014).

1108 A major difference between non-avian reptilian yolk-sac formation is the morphology and
1109 extent of vascularization and cellularization in the yolk sac cavity (Starck, 2021). Birds have a

1110 yolk-sac with absorptive endodermal lining that digests nutrients and send them into blood
1111 circulation (Starck, 2021) whereas snakes, lizards, turtles, and crocodilians have a yolk sac that
1112 becomes invaded by endodermal cells that proliferate and phagocytose yolk material (Blackburn,
1113 2021). In these taxa, yolk material becomes cellularized, digested, and transported by vitelline
1114 vessels to the developing embryo (Blackburn, 2021). Factors involved with cellularization of the
1115 yolk-sac are proposed to include cell cycle regulators and structural proteins (Elinson et al.,
1116 2014). Generation of these cells are suspected to be reliant on processes of angiogenesis and are
1117 likely transcriptionally active (Elinson et al., 2014). Few transcriptomic profiles of yolk-sac
1118 placentas in reptiles have been documented to my knowledge (Griffith et al., 2016). Significant
1119 overlaps in the yolk-sac transcriptomes of human, mice, and chicken—including apolipoproteins
1120 and SLC transporters—however, suggest functional conservation (Cindrova-Davies et al., 2017).

1121 As discussed in a previous section, progesterone inhibits myometrial contractility, but it also
1122 inhibits estrogen-induced hepatic vitellogenin synthesis (Custodia-Lora, Novillo, & Callard,
1123 2004; Callard et al., 1992). Variable progesterone concentrations in circulation throughout
1124 gestation in viviparous squamates may reflect a trade-off to allow estrogen expression to support
1125 hepatic vitellogenin synthesis during embryonic development, thus supporting nutrient
1126 provisioning during the lengthened embryonic retention. Although hepatic vitellogenesis usually
1127 ceases during gestation, vitellogenin synthesis and mother-to-embryo transfer was detected in
1128 one viviparous fish, *Xenotoca eiseni*, during gestation (Iida et al., 2019). Future research should
1129 consider the timing of vitellogenin synthesis throughout the reproductive cycle in gestating and
1130 non-gestating viviparous squamates to investigate this further.

1131

1132 (3) *Evolutionary history of placentrophy in mammals & squamates*

1133 Traditionally, it was thought that placentrophy evolved after viviparity in squamates
1134 (Packard, Tracy, & Roth, 1977; Shine & Bull, 1979). Further research demonstrated that
1135 placentrophy and viviparity evolved simultaneously (incipient matrotrophy) in mammals and
1136 may have in squamates (Blackburn, 1985, 1992, 2005, 2006; Stewart & Eday, 2010). The
1137 incipient matrotrophy model relies on evidence that 1) uterine provisioning of nutrients predates
1138 the origin of viviparity (Blackburn 1985, 1992, 2006), 2) uterine and embryonic tissues have a
1139 close anatomical and physiological association in viviparous taxa and 3) some degree of
1140 placental transfer of organic or inorganic molecules occurs in viviparous taxa (Stewart & Eday,
1141 2010). In squamates, the potential for both incipient matrotrophy and evolution of placentrophy
1142 after viviparity is supported (Stewart & Eday, 2010). Facultative placental nutrient provisioning
1143 and incipient matrotrophy may have driven the evolution of squamates with substantial
1144 matrotrophic nutrient provisioning (Stewart, 2020; Swain & Jones, 2000).

1145 Placentation and implantation are not homologous in mammals compared to squamates
1146 (Griffith, van Dyke & Thompson, 2013). Several placental specializations for gas and nutrient
1147 exchange are unique to mammals including erosion of the uterine mucosa, extensively invasive
1148 implantation, hemochorial contact, retention of a vascularized choriovitelline membrane, and
1149 countercurrent patterns of blood flow (Blackburn, 2005). This enables extensive exchange of
1150 nutrients in addition to water and gas. The vast majority of viviparous squamates have the most
1151 superficial type of chorioallantoic placenta called epitheliochorial placenta (Blackburn, 1993).

1152 Nutrient provisioning through placentrophy is obligate for embryonic development in only
1153 five lineages of squamates, all of which are scincid lizards (Blackburn, 2000; Flemming &
1154 Blackburn, 2003; Ramírez-Pinilla et al., 2011; van Dyke et al., 2014). *Pseudemoia*
1155 *pagenstecheri*, a lizard with a highly specialized placenta, out-performs lecithotrophic oviparous

1156 close relatives in the relative amount of nutrients it transfers to the embryo (Stewart et al., 2009).
1157 *Pseudemoia entrecasteauxii* is a moderately matrotrophic viviparous skink, with roughly half of
1158 embryonic nutrient uptake from the yolk and half through a specialized cyto-epitheliochorial
1159 placenta (Adams et al., 2005; Speake et al., 2004; Stewart & Thompson, 1993, 2009).

1160 Specializations of the chorioallantoic placenta for nutrient provisioning in some squamates
1161 include elaborate specializations for uterine secretion and absorption, including placentomes,
1162 chorionic areolae, hypertrophied uterine mucosa, and chorionic epithelia modified for absorption
1163 (Blackburn, 2005). In squamates, specializations for gas exchange across the chorioallantoic
1164 placenta include decreased diffusion distance between maternal and fetal capillaries, uterine
1165 vascularity, shell membrane deterioration, and modifications of both fetal and maternal blood
1166 properties (Blackburn, 1998, 2005; Blackburn & Lorenz, 2003; Blackburn & Vitt, 2002).

1167 Mammalian placenta-specific genes have deep origins in vertebrates (Rawn & Cross, 2008).
1168 Placentation to support viviparity likely employs genes that are ancestral to the chorioallantois.
1169 However, one study that looked at placentation and gene expression across a small sample of
1170 divergent amniotes found only one gene with a placentrophy-specific pattern of gene expression,
1171 *DIO3* (Griffith, Brandley et al., 2017). In mammals, *DIO3* is an imprinted gene and
1172 preferentially paternally expressed. The authors suggest that the gene may increase offspring
1173 resource uptake during pregnancy in the horse and a viviparous lizard, *Pseudemoia*
1174 *entrecasteauxii*, where it is recruited to the placenta (Griffith, Brandley et al., 2017).

1175

1176 (4) Genes involved with embryonic water, gas, and nutrient transport

1177 Water transport in animals is regulated by a family of molecular water channels called
1178 aquaporins (AQs or AQPs) (Borgnia et al., 1999). In humans, *AQP1*, *AQP3*, *AQP4*, *AQP8* and

1179 *AQP9* are found in the placenta but further research is needed to understand how these influence
1180 water fluxes between maternal and fetal tissues (Damiano, 2011). Transcriptomic analysis on
1181 uterine tissue of the gestating, viviparous skink, *Chalcides ocellatus*, reveal differential
1182 expression of *AQP1*, *AQP3*, *AQP5*, *AQP6*, *AQP8*, *AQP9* and *AQP11* when compared to non-
1183 gestating uteruses (Brandley et al., 2012). In birds, *AQP1* is expressed in the chorioallantoic
1184 membrane, and it is suggested to influence angiogenesis throughout embryonic development
1185 (Ribatti et al., 2002). In a viviparous lizard, *Pseudemoia entrecasteauxii*, *AQP8* and *AQP9* were
1186 more highly expressed in the chorioallantoic placenta compared to the yolk-sac placenta (Griffith
1187 et al., 2016). During gestation in both oviparous and viviparous populations of the reproductively
1188 bimodal skink, *Saiphos equalis*, several genes involved with water homeostasis are upregulated
1189 in the uterus including *AQP1*, *AQP3* and *AQP12B* (Foster et al., 2020). In uteruses of *Saiphos*
1190 *equalis*, *AQP5* and *AQP8* are upregulated during oviparous late gestation compared to viviparous
1191 late gestation. In sheep, *AQP3* is differentially expressed during gestation, where it serves a dual
1192 role of water transport to the embryo and fetal urea export (Johnston et al., 2000). This is similar
1193 to the function of *AQP9* in humans (Damiano, 2011). Immunocytochemistry reveals that *AQP1*
1194 and *AQP3* are expressed in the uterus of the highly placentrophilic South American scincid lizard,
1195 *Mabuya sp.* (Wooding et al., 2010). In *Zootoca vivipara*, *AQP9* is upregulated at midgestation
1196 (Recknagel et al., 2021a).

1197 Some molecules are implicated in the regulation of aquaporins including insulin (INS),
1198 human chorionic gonadotropin (HcG), cyclic adenosine monophosphate (cAMP) and cystic
1199 fibrosis transmembrane conductance regulator (CFTR) (Damiano, 2011). Genes predicted to be
1200 involved with reproduction in *Anolis carolinensis* are enriched for the GO term for cAMP-
1201 mediated signaling (Alföldi, Di Palma, et al., 2011). Further comparative research should be

1202 done to elucidate the functional differences of aquaporins in oviparous and viviparous amniotes
1203 and how they relate to the differing conditions under which these embryos develop.

1204 Genes involved embryonic oxygen transport precede the origin of amniotes. Hemoproteins
1205 arose in evolutionary history well before they were used for placental oxygen transfer (Hardison
1206 1998). In mammals, adult (Alpha: HBA; Beta: HBB, HBD) and embryonic hemoglobins (Alpha:
1207 HBZ, HBA; Beta: HBE, HBG, and HBH) are involved with oxygen transport (Carter, 2012).
1208 Some of these are unique to eutherian mammals following a series of duplication events (Opazo
1209 et al., 2008). However, fetal hemoglobins are found in turtles, lizards, and snakes (Pough, 1980).
1210 HBA, HBB and HBM are all significantly downregulated in the uterine tissue of the viviparous
1211 African Ocellated Skink, *Chalcides ocellatus*, during gestation compared to non-gestation
1212 (Brandley et al., 2012). The oxygen demands of reptile embryos are relatively low until stage 30,
1213 when most oviparous taxa oviposit (Shine & Thompson, 2006). In viviparous and oviparous
1214 species with long egg retention, embryonic demand for maternal provision of oxygen and
1215 removal of CO₂ increases at this stage.

1216 Improper water, gas and nutrient exchange can occur due to poor chorioallantoic blood flow
1217 (Wootton et al., 1977). Thus, viviparous taxa require greater degrees of vascularization and
1218 vasodilation to facilitate enhanced requirements for maternal resources compared to oviparous
1219 taxa. Rather than increasing the size of the placenta, increasingly dense blood vessels can support
1220 fetal growth without compromising space for embryonic growth as occurs in some pigs (Ford,
1221 1997; Vonnahme et al., 2002). Embryonic vascularization and vasodilation are dependent on
1222 signals from the endoderm (Jin et al., 2005; Vokes & Krieg, 2002; Wilt, 1965). In oviparous
1223 individuals of *Saiphos equalis*, populations with extended egg retention, there is expansion of the
1224 uterine vascular bed and thickening of the chorioallantoic tissue that supports increased

1225 embryonic growth in the later portion of oviparous gravidity (Parker et al., 2010). In the
1226 viviparous scincid lizard, *Eulamprus quoyii*, angiogenesis, the formation of new blood vessels,
1227 and expansion of the vessel-dense elliptical area of the uterus is associated with supporting
1228 increased embryonic oxygen demand (Murphy et al., 2010).

1229 Several protein-coding genes are known to be involved with angiogenesis, vascularization,
1230 and vasodilation in utero. One study that examined expression patterns across chickens
1231 (oviparous), horses (viviparous), two viviparous squamates, and one oviparous squamate found
1232 that no examined genes for angiogenesis showed a viviparity-specific expression pattern
1233 (Griffith, Brandley et al., 2017). However, other than the chicken, the only oviparous taxa
1234 included in this study was a reproductively bimodal skink, *Lerista bougainvillii* (Griffith,
1235 Brandley et al., 2017). Alternatively, differential gene expression analyses on oviparous and
1236 viviparous individuals of *Zootoca vivipara*, revealed pathways for angiogenesis enriched in
1237 viviparous female reproductive tissues; and pathways for angiogenesis were enriched across
1238 genes under divergent selection in oviparous and viviparous *Z. vivipara* individuals.

1239 In the uterine tissue of gestating viviparous skinks and rats, several genes for angiogenesis
1240 are upregulated—*EPASI*, *HIF1A* and *VEGFA* (Brandley et al., 2012; Whittington et al., 2015,
1241 2017). Other proteins involved in vascularization and vasodilation in utero include members of
1242 the vascular endothelial growth factor (*VEGF*) gene family, VEGF receptors (*VEGFRs*),
1243 placental growth factor (*PGF*) and nitric oxide synthase (*NOS*) (Blomberg et al., 2010; Chen,
1244 Wang et al., 2015; Gilbert, 2010; Reynolds et al., 2006; Risau, 1997; Torry et al., 2003;
1245 Vonnahme et al., 2001). In *Saiphos equalis*, different homologs of *NOS* experience different
1246 patterns of gene expression across the oviparous and viviparous stages of gestation/gravidity
1247 (Foster et al., 2020). One homolog of *NOS* is upregulated during oviparous late gestation, and

1248 another is upregulated during viviparous late gestation (Foster et al., 2020). Several genes
1249 involved with angiogenesis and vascular morphogenesis are downregulated in the pre-
1250 implantation uterus of a marsupial, the Fat Tailed Dunnart, *Sminthopsis crassicaudata*—
1251 *ADGRA2*, *ADGRB2*, *ANGPTL1*, *EPHB4*, *ISM1*, *PDZRN3*, *RHOJ*, *TNMD*, and *VEGFD*
1252 (Whittington et al., 2018).

1253 In humans, immune factors are also responsible for increasing embryonic blood supply.
1254 Embryonic non-classical MHC class I molecule, HLA-G, and uterine natural killer (uNK) cells
1255 support increased embryonic blood supply (Moffett & Loke, 2006; Rajagopalan et al., 2006). A
1256 similar pattern of utilizing immune properties to support embryonic blood supply has not been
1257 yet identified in squamates.

1258 Lipids are a main energy source for embryos. Lipoprotein lipase (LPL) is an important
1259 enzyme in lipid transport. LPL is significantly expressed on the syncytiotrophoblasts, specialized
1260 placental cells, of humans (Lindegaard et al., 2005) and the endometrium of cows (Forde et al.,
1261 2011), and pigs (Ramsay et al., 1991), where it plays a role in lipid mobilization. A viviparous
1262 lizard, *Pseudemoia entrecasteauxii*, increases capacity for lipid transport toward the end of
1263 pregnancy (Griffith, van Dyke & Thompson, 2013). The uterine tissue of the yolk-sac placenta in
1264 this species had significantly higher expression of LPL than the uterine tissues of the
1265 chorioallantoic placenta (Griffith, van Dyke & Thompson, 2013), leading the authors to suggest
1266 that the yolk-sac placenta is the major site of lipid transport. LPL expression was not detected
1267 during pregnancy in the viviparous skink, *Chalcides ocellatus* (Blackburn, 1992; Brandley et al.,
1268 2012). Instead, lipid transport may be facilitated by fatty acid binding proteins in this species
1269 (Chmurzyńska, 2006; Brandley et al., 2012). These are also active on mammalian placenta
1270 (Haggarty, 2002).

1271 Apolipoproteins are also suitable candidates for transport of fatty acids, cholesterol, and
1272 phospholipids. Five of these (*APOA1*, *APOA2*, *APOA4*, *APOE*, and *APOM*) and *APOA1BP* are
1273 significantly upregulated in the pregnant uterus of the viviparous skink, *Chalcides ocellatus*
1274 (Brandley et al., 2012). *APOA1BP* is also upregulated in the uterus of the chorioallantoic
1275 placenta and yolk-sac placenta compared to non-gestational uterine tissues in *Pseudemoia*
1276 *entrecaeauxii* (Griffith et al., 2016). Additionally, upregulation of 136 genes that encode solute
1277 carrier proteins (SLCs) in the pregnant uterus of *Chalcides ocellatus* are associated with
1278 transport of inorganic ions, metals, glucose, amino acids, peptides, fatty acids, and carboxylic
1279 acids (Brandley et al., 2012).

1280 Supply of amino acids is required for embryonic development. SLCs have important
1281 transport functions, including the transport of amino acids, and thus they are considered to be
1282 important for gestation (Foster et al., 2022). However, a recent study found no overlap in the
1283 amino acid transporting SLCs upregulated in placentas of viviparous placentrophic vertebrates
1284 studied, which included eight representatives from Mammalia, Reptilia, and Chondrichthyes
1285 (Foster et al., 2022). However, *SLC38A3* was upregulated in all viviparous species except *Rattus*
1286 *norvegicus* (Foster et al., 2022).

1287 Cathepsins and phospholipases are important for uterine secretions for embryonic
1288 development in horses, pigs, sheep, and cattle (Bazer, 1975; Satterfield et al., 2007; Song et al.,
1289 2010). Cathepsins are present in yolk sacs of humans and mice. They function to degrade
1290 proteins to free amino acids (Cindrova-Davies et al., 2017). Two genes for cathepsin L (*CTSL1*
1291 and *CTSL2*) are upregulated in the uterus during gestation in *Chalcides ocellatus* (Brandley et al.,
1292 2012). *CTSL* is also upregulated in the uterus during the pre-implantation phase in the Fat-Tailed
1293 Dunnart, *Sminthopsis crassicaudata* (Whittington et al., 2018), and in the uterus of the

1294 chorioallantoic placenta and uterus of the yolk sac placenta during gestation in *Pseudemoia*
1295 *entrecasteauxii* (Griffith et al., 2016).

1296 In viviparous individuals of the reproductively bimodal lizard, *Saiphos equalis*, many genes
1297 for cellular adhesion are upregulated during late gestation (Foster et al., 2020). The authors
1298 postulated that this helps facilitate maternal-fetal signaling and paracellular transport (Foster et
1299 al., 2020). Gao et al. (2019) identified a set of genes in *Phrynocephalus vlangalii* that were
1300 differentially expressed in the uterus during the stage of placentation and these enriched GO
1301 terms functionally related to the process of placentation. This included an estrogen receptor
1302 (*ESRI*) and two growth factor receptors (*GHR* and *IGFIR*) (Gao et al., 2019).

1303 Finally, the proteomes of the ovary and placenta from obligately placentrophic *Mabuya*
1304 lizards can further serve as a useful resource for examining nutrient provisioning in squamates
1305 (Hernández-Díaz et al., 2017). In the placenta they found protein expression involved with
1306 nutrient metabolism, transport, protein synthesis, and embryonic development (Hernández-Díaz
1307 et al., 2017).

1308

1309 (5) *Uterine glands: adenogenesis, placenta development and histotrophy*

1310 In addition to their role in eggshell deposition in oviparous taxa, uterine glands also secrete
1311 growth factors and cytokines that support placental development in mammals. In humans, these
1312 include transforming growth factor- β (TGF- β), epidermal growth factor (EGF), vascular
1313 endothelial growth factor (VECG), and leukemia inhibitory factor (LIF) (Hempstock et al.,
1314 2004). In eutherians, TGF- β supports placental development by regulating proliferation and
1315 invasion rates of placental cells lines (Caniggia et al., 2000; Hempstock et al., 2004; Lafontaine
1316 et al., 2011).

1317 Histotrophy (also called histiotrophy) occurs when nutrients are secreted into the uterine
1318 lumen from vesicles of the columnar epithelial cells of the uterus and taken up by the embryo.
1319 Histotrophic nutrient provisioning is documented across amniotes including marsupials
1320 (Whittington et al., 2018), several ungulate taxa (Bazer et al., 2011; Han et al., 2016; Gao et al.,
1321 2009), humans (Burton et al., 2002), and appear to occur in some viviparous squamates (van
1322 Dyke et al., 2014). In humans, histotrophic nutrient provisioning occurs during the first trimester.
1323 The intervillous space is filled with fluid containing uterine gland secretions that get
1324 phagocytosed by the syncytiotrophoblasts and are the initial nutrient source for the fetus (Burton
1325 et al., 2002). Two of these glycoproteins are epithelial mucin (*MUC1*) and glycodefin A (*GdA*)
1326 (Burton et al., 2002). Interestingly, the *MUC15* gene is upregulated during gravidity/gestation in
1327 the uterus of oviparous and viviparous *Saiphos equalis* individuals (Foster et al., 2020). This also
1328 occurs in the chorioallantoic placenta of *Pseudemoia entrecasteauxii* during gestation (Griffith et
1329 al., 2016). Several mucins are expressed in the uterus in non-gravid and gravid samples from
1330 oviparous individuals of *Lerista bougainvillii* and *Lampropholis guichenoti* (Griffith et al.,
1331 2016).

1332 A survey of viviparous squamates with modest to extensive placentrophy revealed
1333 prevalence of histotrophic nutrient provisioning rather than hemotrophy, transfer of nutrients
1334 between maternal and fetal blood streams (Blackburn 2015). Embryos of *Chalcides chalcides*
1335 have extensive placentrophy that supports substantial maternal nutrient provisioning and
1336 histotrophy (Blackburn, 2015a). Histotrophy may lessen parent-offspring conflict and give the
1337 mother the control over nutrient provisioning compared to hemotrophy (Blackburn, 2015b).

1338 *Chalcides ocellatus* has less extensive placentrophy than *C. chalcides* but the gestating uterus
1339 still illustrates expression of many genes associated with organic and inorganic nutrient transport

1340 (Blackburn, 2015a). Multiple *TGF-β* genes are differentially expressed in the uterus during
1341 gestation in *C. ocellatus*, however most these are downregulated compared to non-gestational
1342 uterine tissue (Murphy et al., 2012). The influence of *TGF-β* on placental development and
1343 nutrient provisioning in *Chalcides spp.* remains to be explored to my knowledge. A TGF-β
1344 receptor (*TGFBRI*) was associated with placental development in *Phrynocephalus vlangalii*
1345 (Gao et al., 2019).

1346 Essential to histotrophy is adenogenesis, the generation of endometrial glands. Adenogenesis
1347 allows for the secretion of histotrophs. The period of early development during which
1348 adenogenesis occurs is highly variable among vertebrates but it is required for embryonic
1349 survival (Gray et al., 2001, 2002; Spencer & Bazer, 2004). Some genes involved with
1350 adenogenesis in sheep are insulin-like growth factor 1 (*IGF-1*), *IGF-2*, *PAX2*, *LHX1* (also known
1351 as *LIM1*) and *EMX2*, genes in the abdominal-B HOXA cluster, members of both *Wnt* and
1352 Hedgehog (*Hh*) gene families (Fazleabas et al., 2004), prolactin (*PRL*), fibroblast growth factor 7
1353 (*FGF7*), *FGF10*, *FGFR2IIIb*, hepatocyte growth factor (*HGF*), a receptor tyrosine kinase (*c-*
1354 *Met*), and cadherins (Fazleabas, 2007).

1355 In the gestating uterus of *Chalcides ocellatus*, insulin-like growth factor-binding protein 5
1356 (*IGFBP5*) is one of the most significantly downregulated genes compared to non-gestational
1357 uterine tissue (Brandley et al., 2012). *IGFBP5* is evolutionarily conserved and multifunctional,
1358 with an important role in regulating IGF signaling, including that of *IGF-1* and *IGF-2* (Duan &
1359 Allard, 2020). Other than adenogenesis in sheep, IGFs serve an important role in the growth of
1360 fetal and maternal tissues in mammals (Gibson et al., 2001; Kampmann et al., 2019).

1361 Genes involved with histotrophic secretion in the marsupial *Sminthopsis crassicaudata*
1362 include *AP4SI*, *HYOU1*, and *SRPRA* (Whittington et al., 2018). Nutrient transporters

1363 significantly upregulated at this time are *APOL6* (cholesterol transport (Baardman et al., 2013)),
1364 *PLA2G10* (hydrolysis of fatty acids during pregnancy (Miele et al., 1987)) and a wealth of SLCs
1365 (solute carrier proteins for transport of sugar, ions, anions, glucose, fatty acids, calcium and zinc
1366 (Whittington et al., 2018)). Subsequent research has identified downregulated of *HYOUI* at early
1367 and mid-gestation; and downregulation of *SRPRA* at mid-gestation in viviparous *Zootoca*
1368 *vivipara* compared to oviparous (Recknagel et al., 2021a). In a reproductively bimodal skink,
1369 *Saiphos equalis*, *PLA2G10* is upregulated during viviparous late gestation compared to oviparous
1370 late gestation (Foster et al., 2020). Upregulation of SLCs also occurs in the viviparous skink
1371 *Chalcides ocellatus* (Brandley et al., 2012; Van Dyke et al., 2014) and in the uterus during
1372 pregnancy in the grey short-tailed opossum, *Monodelphis domestica* (Hansen, Schilkey & Miller,
1373 2016).

1374 Uterine glands are also important for secretions of eggshell precursors. I speculate that genes
1375 involved with adenogenesis of uterine glands may be similarly used to support histotrophic
1376 nutrient provisioning during transitions to viviparity, but further research is necessary.

1377 Specialized uterine areolar glands are found in some *Mabuya* lizards, a genus with oviparous
1378 species and viviparous species that utilize placentrophy and histotrophy (Corso et al., 1988,
1379 2000; Jerez & Ramírez-Pinilla, 2001; Ramírez-Pinilla, 2006; Vieira et al., 2007; Visser, 1975).

1380 Transcriptomic research focused on histotrophic nutrient provisioning, placental development,
1381 and secretions of eggshell precursors in oviparous and viviparous *Mabuya spp.* would
1382 complement literature on the genus.

1383

1384 (6) *Discussion & future directions—embryonic nutrients, gas, and water supply*

1385 Many genes for placental functions in mammals have deep origins in vertebrates (Rawn &
1386 Cross, 2008). In pairwise comparisons of different viviparous amniotes, there is overlap in
1387 hormones and proteins (SLC superfamily, insulin-like growth factors, aquaporins and solute
1388 carrier proteins, etc.) involved in uterine remodeling, placentation, and placental transport. While
1389 shared genes are recruited to the uterus across viviparous amniotes (Recknagel et al 2021a), there
1390 are no shared genes recruited to the placenta across viviparous reptiles, mammals, and sharks
1391 (Foster et al., 2022). Evolutionarily, this suggests higher conservation of the regulatory networks
1392 associated with uterine responses to viviparity than placental responses to viviparity. The
1393 relationship of these findings to embryonic nutrient provisioning and the evolution of the
1394 amniotic egg requires further investigation. Supplementary Table 2 illustrates how genes
1395 mentioned in text for water, gas, and nutrient transport are expressed in reproductive tissues of
1396 squamates during gestation and gravidity.

1397 If specific genes or physiological processes impact more than one of the Main Five
1398 categories, it could have a disproportionate influence on transitions. Such an overlap has already
1399 been identified in *Zootoca vivipara*, where 11 genes are associated with both eggshell traits and
1400 gestation length (Recknagel et al., 2021a). The solute carrier (*SLC*) gene superfamily is involved
1401 with both nutrient transport (Brandley et al., 2012; Whittington et al., 2018) and eggshell
1402 deposition (Yang et al., 2020). Adenogenesis is essential for histotrophic nutrient provisioning
1403 and secretion of eggshell precursors. Additionally, progesterone production influences both
1404 uterine quiescence, which is an important state to maintain in lengthened embryonic retention,
1405 and it also inhibits hepatic vitellogenesis, an important process for lecithotrophic nutrient
1406 provisioning. Thus, examining the role of *SLC* gene superfamily members, processes of

1407 adenogenesis, and progesterone production during embryonic development in oviparous and
1408 viviparous squamate may reveal how interconnectivity of the Main Five are.

1409

1410 **V. Embryonic Calcium Provisioning**

1411

1412 The embryonic growth stage requires the greatest demand of calcium (Ecay et al., 2017;
1413 Packard & Packard, 1984; Stewart & Ecay, 2010). To support this, peak uterine concentrations
1414 of calcium are highest during either eggshell deposition or during the embryonic growth stage, in
1415 oviparous and viviparous taxa, respectively (Linville et al., 2010; Stewart et al., 2009).
1416 Regardless of parity mode, embryonic metabolism drives calcium uptake (Packard & Packard,
1417 1984). The calcium source(s) utilized have clade-specific implications on the genomic and/or
1418 physiological changes required to transition between parity modes.

1419

1420 *(1) Phylogenetic context of embryonic calcium sources*

1421 Calcium can be acquired by the embryo in three forms: calcium carbonate in the eggshell,
1422 calcium bound to proteins and lipids in the yolk, and/or free ionic calcium from maternal
1423 delivery through the placenta (Stewart & Ecay, 2010). These correspond with five calcium
1424 mobilization patterns: 1) Birds, turtles and crocodiles predominately depend on the eggshell; 2)
1425 Most squamates, regardless of parity mode, predominately depend on the yolk; 3) Some
1426 squamate species are reliant on both the eggshell and yolk; 4) Some viviparous squamate species
1427 are reliant on both the yolk and placenta; and 5) therian mammals and rare viviparous squamates
1428 predominately depend on the placenta (Blackburn, 2015a; Hoenderop, Nilius, & Bindels, 2005;
1429 Jenkins & Simkiss, 1968; Kovacs, 2015; Packard, 1994; Packard & Seymour, 1997; Stewart et

1430 al., 2009, 2009; Stewart & Ecy, 2010; Thompson, Stewart et al., 1999; Thompson, Stewart, &
1431 Speake, 2000; Ramírez-Pinilla, 2006).

1432 From an evolutionary perspective, squamate eggs might serve as the best models of the
1433 ancestral amniote egg. Unlike birds, oviparous squamates generally rely on yolk calcium rather
1434 than eggshell calcium. The yolk sac of non-avian reptiles is a good model for the transition
1435 between the egg of anamniotes and amniotes (Blackburn, 2020). Taken together and given that
1436 hard calcified eggshells of Archelosaurs are likely derived (as discussed in section III.3)—
1437 squamate eggs may have the closest resemblance to the ancestral amniote egg. Interestingly, to
1438 my knowledge, oviparous squamates do not sequester calcium from the eggshell into the yolk
1439 during incubation (Packard, 1994).

1440

1441 *(2) Hypotheses on calcium mobilization and the evolution of parity modes*

1442 It was hypothesized that predominant reliance on eggshell calcium should constrain lineages
1443 to oviparity because the evolution of viviparity would result in a lost calcium source (hereafter
1444 eggshell calcium constraint hypothesis) (Stewart & Ecy, 2010; Packard et al., 1977; Packard &
1445 Packard, 1984). This hypothesis suggested that viviparity should only evolve in lineages
1446 predominately reliant on yolk calcium (Packard et al., 1977; Packard & Packard, 1984).
1447 Fittingly, birds, turtles and crocodilians generally rely on eggshell calcium, and they are
1448 constrained to oviparity (Anderson et al., 1987). The eggshell calcium constraint hypothesis
1449 holds true for most viviparous squamates that rely heavily on yolk calcium (Stewart & Castillo,
1450 1984; Stewart & Ecy, 2010; van Dyke et al., 2014).

1451 Subsequent research revealed that viviparity is not constrained by a prerequisite reliance on
1452 yolk calcium. Oviparous scincid skinks studied thus far are intermediately reliant on eggshell and

1453 yolk calcium (Linville et al., 2010; Shadrix et al., 1994; Stewart et al., 2009; Stewart &
1454 Thompson, 1993; Thompson et al., 2001). Calcium placentrophy contributes substantially to
1455 embryonic development in several viviparous squamates including *Pseudemoia entrecasteauxii*,
1456 *Eulamprus quoyi*, *Zootoca vivipara*, *Saiphos equalis*, and a species of *Mabuya* lizard (Ecay et al.,
1457 2017; Linville et al., 2010; Ramírez-Pinilla, 2006; Ramírez-Pinilla et al., 2011; Stewart &
1458 Thompson, 1993). These taxa, with the exception of *Zootoca vivipara*, are in the family
1459 Scincidae (Burbrink et al., 2020), which is also the family with the most independent origins of
1460 viviparity in squamates (Blackburn, 1982, 1999; Pyron & Burbrink, 2014).

1461 To understand the breadth of physiological conditions from which oviparity and viviparity
1462 evolve in squamates, future research should examine calcium transport in other lineages. Studies
1463 focused on snakes would be particularly informative given the sparse literature on them.

1464 *Helicops angulatus*, a reproductively bimodal water snake from South America, is an ideal
1465 model for this (Braz et al., 2016). Thus far, many oviparous snakes are known to be
1466 intermediately reliant on yolk and eggshell calcium. This has not precluded viviparity from
1467 evolving in these lineages.

1468 The presence of embryos during extended embryonic retention may trigger positive feedback
1469 stimuli for continued uterine calcium secretions which may support placental calcium transport,
1470 and thus incipient calcium matrotrophy (Stewart & Ecay, 2010). This is postulated to resemble
1471 the hormonal and mechanical stress mechanisms implicated in avian eggshell formation and
1472 uterine calcium secretions (Bar, 2009a; Stewart & Ecay, 2010). The influx of calcium late in
1473 viviparous gestation may be triggered in part by embryonic growth that over distends the uterus.
1474 This is seen in studies on myometrial stretch in mammals when uterine overdistention triggers
1475 spikes in calcium (Kao & McCullough, 1975; and see e.g. Wray et al., 2015).

1476 Dramatic changes to activity in chorioallantois should not be required during parity mode
1477 transitions because these homologous tissues (Metcalf & Stock, 1993) transport calcium
1478 regardless of parity mode (Ecay, Stewart & Blackburn, 2004; Tuan & Scott, 1977; Tuan &
1479 Knowles, 1984; Tuan et al., 1978, 1986). Specialized placental structures in some viviparous
1480 squamates enhance calcium provisioning but specialization is not required for placental calcium
1481 transport (Stewart et al., 2009; Stewart & Ecay, 2010; Thompson et al., 2000). Loss of
1482 chorioallantoic calcium transporting capacity would be disadvantageous to either parity mode.
1483 Growing research reveals that, like mammals, placentrophy and viviparity can evolve
1484 concurrently in squamates (Blackburn, 2015a; Ecay et al., 2017; Stewart & Ecay, 2010).

1485 Placing these previously proposed models in a phylogenetic context, the calcium transport
1486 method of oviparous ancestors likely has an influence on the method of calcium transport used
1487 for viviparous taxa—matrotrophic calcium provisioning, lecithotrophic calcium provisioning, or
1488 a combination of the two. Consistent with the basal cap hypothesis—when viviparity arises from
1489 oviparous ancestors with embryos that depended predominately on eggshell calcium, this should
1490 favor a transition to viviparity via incipient calcium matrotrophy because the chorioallantois
1491 already plays the major role in transporting calcium from the eggshell to the embryo. Since the
1492 reproductive mode and calcium provisioning of oviparous ancestors are essentially unknown,
1493 researchers can use the closest oviparous relatives as proxies. Similarly, viviparous taxa that are
1494 in close phylogenetic proximity to oviparous taxa that depend on lecithotrophic calcium
1495 provisioning should remain reliant on yolk calcium. Together, these guidelines provide a
1496 framework from which researchers can form hypotheses about the calcium provisioning method
1497 of a viviparous lineage if the calcium provisioning method of oviparous close relatives are
1498 known, or vice versa. Measurements of the proportional contribution of different calcium sources

1499 during development has only been done in select taxa (e.g. Packard, 1994; Stewart, 2013;
1500 Stewart & Ecy, 2010; Stewart, Ecy & Blackburn 2004). Once validated, the framework (i.e.,
1501 the calcium provisioning method of close relatives) can help increase the speed at which science
1502 measures and infers the evolutionary history of calcium provisioning across amniotes and
1503 squamates. Collection of this data across the squamate phylogeny may enable assignment of
1504 these hypotheses to specific clades.

1505 Embryonic calcium source could have implications on the physiological changes required to
1506 transition between parity modes. Reliance on yolk calcium should render, essentially, no
1507 mechanistic changes for calcium transport. On the other hand, incipient calcium matrotrophy
1508 requires regulatory changes in the uterus, like timing of calcium secretions (Griffith et al., 2015).
1509 However, regardless of parity mode 1) the uterus secretes calcium, 2) the chorioallantois
1510 transports calcium and 3) embryonic metabolism drives uptake of calcium. Assuming maternal
1511 tissue remains responsive to embryonic metabolism, the joint evolution of matrotrophic calcium
1512 provisioning with viviparity may require little to no physiological adjustments.

1513 The diversity of embryonic calcium provisioning patterns in viviparous squamates may not
1514 be fully explained by the eggshell calcium constraint hypothesis (Packard et al., 1977; Packard &
1515 Packard, 1984) or incipient calcium matrotrophy (Stewart & Ecy, 2010). Both hypotheses
1516 implicitly assume that viviparity equates to a lost eggshell. In one viviparous squamate, *Haldea*
1517 *striatula*, and in viviparous populations of two reproductively bimodal lizards, *Zootoca vivipara*
1518 and *Saiphos equalis*, the calcified eggshell is considered as a component of the placenta (Stewart,
1519 2013). Some other viviparous squamates have transient calcified patches on their embryonic
1520 membranes (Blackburn, 1998; Heulin, 1990, 2005; Qualls, 1996) suggesting that uterine calcium
1521 secreting capabilities in early gestation may be retained in some viviparous lineages. In the case

1522 of reversals, it remains unknown how the uterus shifts back to early calcium secretions after
1523 ovulation (Blackburn, 2015b; Griffith et al., 2015).

1524

1525 *(3) Embryonic calcium provisioning mechanisms*

1526 In vertebrates, specialized tissues that recover environmental calcium and transport it into
1527 blood circulation maintain conserved mechanisms for intracellular calcium transport (Bronner
1528 2003; Hoenderop et al., 2005). These include the uterus, chorioallantoic tissues, and yolk
1529 splanchnopleure (Bronner, 2003; Hoenderop et al., 2005; Stewart, 2013). Therefore, uterine and
1530 embryonic tissues may be pre-adapted for maternal and embryonic calcium provisioning.

1531 In birds, a sub-compartment of the mammillary layer of the eggshell is the calcium reserve
1532 body (Chien et al., 2009), which contains microcrystals of calcite that get dissolved and
1533 transported as calcium to the embryo (Chien et al., 2009). Calcium is eroded from the eggshell
1534 by acid released from villus cavity cells (VCCs) in chorioallantoic membrane (Anderson, Gay,
1535 and Schraer, 1981; Narbaitz et al., 1981; Packard & Lohmiller, 2002; Simkiss, 1980). This
1536 increases the carbonic anhydrase activity of the cells enabling calcium to be released into the
1537 cavity between the eggshell and the chorionic epithelium, where it is taken up by capillary
1538 covering cells (CCCs) in chorioallantoic membrane (Coleman & Terepka, 1972). In some
1539 species this erosion leads to a gradual weakening of the eggshell that facilitates hatching (Chien,
1540 Hincke & McKee, 2008). In chickens, transcalcin, a calcium binding protein, is credited for the
1541 calcium transporting capacity of the chorioallantoic membrane (Tuan & Knowles, 1984; Tuan &
1542 Ono, 1986; Tuan & Scott, 1977; Tuan et al., 1978, 1986). The presence of VCCs and CCCs in
1543 the chorioallantois of viviparous squamates would indicate a known route through which calcium
1544 can be absorbed.

1545 Transcellular calcium transport has been modeled as a three-step process involving proteins
1546 calbindin-D9K, calbindin-D28K, and the highly calcium-specific ion channels of the transient
1547 receptor potential vanilloid gene family (*TRPV5* and *TRPV6*) (Stewart & Ecaj, 2010). Across
1548 vertebrates, this machinery is shared in epithelial tissues with significant roles in calcium
1549 transport (Hoenderop et al., 2005). Estrogen and vitamin D3 have regulatory roles in this
1550 process.

1551 Calbindin-D9K, calbindin-D28K, *TRPV5*, and *TRPV6* is involved with calcium exchange in
1552 multiple organs of birds, squamates, and mammals. Broadly, activity of calbindin-D9K and/or
1553 calbindin-D28K is associated with patterns of calcium absorption in the mammalian kidney and
1554 uterus (Bindels, 1993; Luu et al., 2004), murine uterus and placenta (Lafond & Simoneau, 2006;
1555 Koo et al., 2012), and chicken duodenum and uterus (Bar, 2009b; Yang et al., 2013). In humans,
1556 calbindin-D9K and calbindin-D28K are critical to the active transport of Ca²⁺ across placental
1557 cells (Faulk & McIntyre, 1983; Belkacemi, Simoneau & Lafond, 2002; Belkacemi et al., 2004).
1558 A study on rats suggests that calbindin-D9K increases by over 100-fold in the last 7 days of
1559 gestation (Glazier et al., 1992), when the embryo gains the majority of calcium. *TRPV6* is
1560 involved with maternal-fetal calcium transport in mice (Suzuki et al., 2008). Increased *TRPV6*
1561 and calbindin-D28K expression occurs during eggshell formation in chickens (Yang et al.,
1562 2013). Given the involvement of these genes in both eggshell deposition and embryonic calcium
1563 transport, squamates may have exploited this pathway to support transitions. Expression of these
1564 genes during gestation or gravidity in squamates has been detected (e.g. calbindin-d9K in
1565 *Saiphos equalis*, and calbindin-d28k in *Zootoca vivipara*) (Foster et al., 2020; Recknagel et al.,
1566 2021a), and is expanded upon in the following paragraphs.

1567 In several highly matrotrophic lizards, embryonic uptake of calcium is associated with
1568 placental expression of calbindin-D28K (Stewart et al., 2009; Stinnett et al., 2011, 2012). In both
1569 oviparous and viviparous embryos of *Zootoca vivipara*, sharp increase in calcium uptake in late
1570 development coincides with increased calbindin-D28K and PMCA by the chorioallantois
1571 (Stewart et al., 2009, 2011). In oviparous corn snakes, *Pantherophis guttatus*, expression of
1572 calbindin-D28K in the yolk-sac and chorioallantoic membrane coincides with growth of these
1573 tissues and calcium transport activity (Ecay et al., 2004). The chorioallantois of other lizards and
1574 snakes transport calcium to the embryo and express calbindin-D28K and PMCA (Blackburn,
1575 2004; Ecay et al., 2004; Stewart et al., 2010; Stinnett et al., 2012).

1576 Viviparous embryos of *Zootoca vivipara*, a reproductively bimodal lizard, incubated *ex utero*
1577 respond to availability of calcium by increasing expression of calbindin-D28K (Ecay et al.,
1578 2017). In this species, embryonic recognition of environmental calcium stimulates a transcellular
1579 calcium transporting mechanism and may also alter chorioallantoic membrane paracellular
1580 permeability to calcium (Ecay et al., 2017). The authors proposed that there is a calcium sensing
1581 receptor (CaSR) on chorionic epithelial cells to support this in both oviparous and viviparous
1582 *Zootoca vivipara* embryos (Ecay et al., 2017), similar to the CaSRs expressed by vertebrate cells
1583 involved in calcium homeostasis (Brennan et al., 2013).

1584 As mentioned earlier, PMCA activity is associated with eggshell deposition in birds and
1585 oviparous squamates (Bar, Rosenberg, & Hurwitz, 1984; Hincke et al., 2012; Wasserman et al.,
1586 1991). PMCA is also crucial for calcium transport in late embryonic development in rats (Glazier
1587 et al., 1992). In viviparous scincid lizards, *Niveoscincus metallicus*, *N. ocellatus*, and
1588 *Pseudemoia spenceri*, PMCA was expressed in uterine glandular and surface epithelia during
1589 pregnancy but only *P. spenceri* expressed it throughout gestation (Herbert et al., 2006). When

1590 PMCA was not detected by immunoblotting in the yolk splanchnopleure of *Haldea striatula*, a
1591 viviparous snake that relies predominately on yolk calcium (Stewart, 1989; Fregoso, Stewart, &
1592 Ecay, 2010), NCXs were proposed as an alternative transporter of calcium (Fregoso et al., 2012).
1593 NCXs are important for placental calcium transport in humans (Belkacemi et al., 2005).

1594 Calcitropic hormones, those involved with calcium transport, and phosphotropic hormones,
1595 those involved with phosphorous transport, operate via an interconnected pathway (Andrukhova
1596 et al., 2016; Biber, Hernando & Forster, 2013; Blaine, Chonchol & Levi, 2015; Erben &
1597 Andrukhova, 2015). Phospho- and calcitropic hormones are important regulators of fetal serum
1598 mineral concentrations (Kovacs, 2015). Evidence from viviparous amniotes suggests that these
1599 are suitable candidates for embryonic calcium provisioning. In mice, genes encoding parathyroid
1600 hormone (*PTH*) and *PTH*-related peptide (*PTHrP*) are important regulators of placental calcium
1601 transport (Kovacs et al., 1996; Simmonds et al., 2010). A non-exhaustive list of additional
1602 candidates for embryonic calcium provisioning include fibroblast growth factor 23 (Bar, 2009a;
1603 Erben & Andrukhova, 2015; Stewart & Ecay, 2010), the annexin gene family (Matschke et al.,
1604 2006), carbonic anhydrase (Narbaitz et al., 1981; Tuan & Knowles, 1984), and calcium binding
1605 proteins (CaBPs) can be found in the referenced literature.

1606

1607 (4) *Discussion & future directions—calcium provisioning and parity mode evolution*

1608 Phylogenetic frameworks enable researchers to make broader testable hypotheses about the
1609 evolutionary history of calcium provisioning in specific clades. Such a framework is proposed in
1610 section V.2 to infer ancestral parity modes in the context of calcium provisioning in amniotes.
1611 Implications gleaned from taxon-specific studies can be explored in distantly related analogous
1612 groups.

1613 Genes involved with calcium transport in uterine and embryonic tissues have been described
1614 across mammals, birds, and reptiles. Like other amniotes, activity of calbindin-D28K and PMCA
1615 supports embryonic calcium provisioning across diverse oviparous and viviparous squamates.
1616 Their involvement with both eggshell deposition and embryonic calcium provisioning makes
1617 these particularly interesting candidates for parity mode evolution. The regulatory influence of
1618 other molecules in calcium transport, like *PTH*, *PTHrP* and NCXs has not been evaluated
1619 thoroughly in squamates. Additional reviews on mechanisms of embryonic calcium provisioning
1620 in squamates can be found in the literature (Stewart, 2013; Stewart & Eday, 2010).

1621 Additionally, I add a speculation. Perhaps lineages with incipient calcium matrotrophy more
1622 feasibly reverse to oviparity because of the continued role of the uterus in calcium provisioning.
1623 However, this hypothesis only holds up if maternal provisioning of calcium is not synonymous
1624 with maternal provisioning of all nutrients.

1625

1626 **VI. Maternal-Fetal Immune Dynamics**

1627

1628 Medawar (1953) pointed out the paradigm between the peripheral body's normal attack
1629 response to allografts (foreign tissue) and uterine tolerance to embryos (Medawar, 1953). This
1630 was inspired by earlier work by Ray Owen (Owen, 1945). Stricter regulation of the maternal and
1631 fetal immune systems is expected for viviparous reproduction because of contact between uterine
1632 and embryonic tissues. Oviparity may pose less of an immunological challenge. Medawar
1633 suggested barriers, inertness and/or immunosuppression enable pregnancy. This formed the
1634 foundation of decades of medical research on immune dynamics between maternal, embryonic,
1635 and paternal immune factors in utero.

1636 In recent years, there was a call for a reappraisal of Medawar's paradigm (Chaouat, 2010,
1637 2016; Moffett & Loke, 2004, 2006; Mor et al., 2011; Stadtmayer & Wagner, 2020b; Yoshizawa
1638 2016). Moffett & Loke (2006) caution against conceptualizing embryos as analogs of allografts.
1639 To my knowledge, this perspective has yet to reach the evolutionary literature on squamate
1640 parity mode evolution (Foster et al., 2020; Graham et al., 2011; Gao et al., 2019; Murphy &
1641 Thompson, 2011; van Dyke, Brandley, & Thompson, 2014; Murphy, Thompson, & Belov, 2009;
1642 Recknagel et al., 2021a). Importantly, challenges to Medawar's paradigm do not preclude
1643 immunological responses to viviparity. They simply suggest that the immune environment of the
1644 uterus is uniquely evolved to support exposure to foreign tissue.

1645 The uterine immune system has a distinct evolutionary history from the periphery. It enables
1646 cooperative dynamics with foreign tissues. It supports fertilization and early embryonic
1647 development. This should have started evolving, distinct from the periphery, since internal
1648 fertilization first originated. To contextualize this, I discuss the changing landscape of
1649 immunological research at the maternal-fetal interface and what it means in the context of
1650 amniote parity mode evolution. Overall, I hope readers consider how the uterus evolved to
1651 support internal gestation, and which model systems may be appropriate to investigate this.

1652 Most literature on maternal-fetal immune dynamics limits itself to mammals. Squamates may
1653 serve as a better comparative model for understanding the evolution of the uterine immune
1654 system. Active research on the peripheral reptilian immune system (Zimmerman et al., 2010,
1655 2020) and uterine immune activity in squamates (Graham et al., 2011; Hendrawan et al., 2017;
1656 Murphy et al., 2009; Paulesu et al. 1995, 2008, 2005) will support future insights on this.

1657

1658 *(1) Comparing amniote immune systems*

1659 Cellular components of the innate immune system are conserved across jawed vertebrates
1660 (Uribe et al., 2011; Zimmerman et al., 2010). The general machinery of the adaptive immune
1661 system is ancient despite divergences and convergences across all domains of life (Ghosh et al.,
1662 2011; Morales et al., 2017; Müller et al., 2018; Rimer et al., 2014). Diversification of antigen
1663 receptor genes likely occurred independently in a lineage-specific fashion (Boehm et al., 2018).
1664 Compared to mammals, the avian immune system requires less antigen (Larsson et al., 1998).
1665 Birds also have faster but shorter antibody responses, potentially due to their higher body
1666 temperatures (Zimmerman, 2010).

1667 Reptiles have the same general components of the mammalian immune system (Zimmerman,
1668 2020). However, the reptilian immune system may not fit neatly into the two arms of mammalian
1669 immune systems—innate and adaptive (Zimmerman, 2010; 2020). Expanding upon this is
1670 beyond the scope of this review, but it is worth considering in future evolutionary research.
1671 Squamates may serve as a better comparative model for understanding the evolution of the
1672 uterine immune system. Active research on the peripheral reptilian immune system (Zimmerman
1673 et al., 2010, 2020) and uterine immune activity in squamates (Graham et al., 2011; Hendrawan et
1674 al., 2017; Murphy et al., 2009; Paulesu et al. 1995, 2008, 2005) will support future insights. I
1675 refer readers to articles by Zimmerman et al. (2010, 2020) and Ghorai et al. (2018), and the book
1676 by Williams (2012) for more information on the avian immune system.

1677

1678 (2) *Medawar's paradigm*

1679 Tolerance toward the foreign fetus was postulated to occur through immunological inertness,
1680 immunosuppression or immunotolerance mechanisms (Medawar, 1953). Theoretically,
1681 immunotolerance could be established if there are relatively small quantities of alloantigens

1682 present, resulting in regulatory responses rather than activating responses (Pradeu, 2011).
1683 Contradicting this, the larger the alloantigen difference between the mother and embryo the
1684 bigger and healthier the placenta is in rats (Chaouat et al., 2010). In humans, divergent HLA
1685 profiles between mother and embryo do not lead to detrimental immune responses (Tilburgs,
1686 Scherjon, & Claas, 2010). Instead, cooperative inflammatory responses between maternal and
1687 fetal tissues support reproduction (Stadtmauer et al., 2020a). In humans, microchimeric cell
1688 populations, presence of cells from one individual in another genetically distinct individual, are
1689 now considered a normal expectation of pregnancy (Nelson, 2012).

1690 In his 1991 Nobel Lecture, Medawar acknowledged that maternal and embryonic tissues
1691 have regular exposure to alloantigens (Medawar, 1991). It has become clear that the maternal
1692 immune system actively responds to fetal alloantigen rather than responding solely with
1693 ignorance or anergy (Arck & Hecher, 2013). Neither maternal immunosuppression/privilege nor
1694 embryonic inertness/immaturity fully explain immune dynamics during gestation in mammals,
1695 including those with the simple epitheliochorial placentation (Chaouat et al., 2010; Chavan,
1696 Griffith & Wagner, 2017; Moffett & Loke, 2004, 2006; Stadtmauer & Wagner, 2020a).

1697

1698 *(3) Perspectives on the evolution of the uterine immune system*

1699 Viviparous reproduction existed eons before the origin of mammals and, to my knowledge,
1700 no evidence suggests there was immune conflict within these taxa (Chaouat, 2016). Placentrophy
1701 existed as far back as the invertebrate clade Bryozoa (Ostrovsky, 2013; Schwaha et al., 2019),
1702 suggesting an ancient history for supportive maternal-fetal immune dynamics. Differing from
1703 Medawar's paradigm, Polly Matzinger, who proposed the 'danger model' for the immune system

1704 (Matzinger, 2007), wrote “Reproduction cannot be a danger. It does not make evolutionary
1705 sense” (Chaouat, 2016).

1706 In mammals, immunological cells at the maternal-fetal interface may not function through
1707 self-non-self-discrimination, as they are understood to function in the rest of the body (Chaouat,
1708 2016; Moffett & Loke 2004, 2006). The ‘maternal-fetal interface’ may be better conceptualized
1709 as ‘maternal-fetal intra-action’ given the dynamics between maternal and fetal immune systems
1710 in mammals (Yoshizawa, 2016). It is unclear if these insights apply to other viviparous amniotes.

1711 In mammals, immune factors in the uterus and placenta appear to be specifically evolved to
1712 support maternal-fetal immune dynamics. Several cell types have unique functions and/or
1713 phenotypes in utero—uterine NK (uNK) cells, uterine macrophages, uterine T regulatory cells
1714 (Faas & de Vos, 2017; Mold et al., 2008, 2010; Mold & McCune, 2011). An immunosuppressive
1715 antigen, HLA-G, is almost exclusively expressed by trophoblasts (Faulk & Temple, 1976;
1716 Kovats et al., 1990; Rajagopalan & Long, 2012; Rouas-Freiss et al., 1997). Taken from an
1717 evolutionary perspective, this suggests that the uterine immune system in viviparous mammals
1718 evolved unique responses to allogenic tissues that differ from the periphery. Whether the
1719 evolution of this system predates mammals remains to be explored, to my knowledge.

1720 It is suggested that viviparous reproduction is immunologically compatible in species with
1721 less active adaptive immune system, like sharks (Chaouat, 2016). In these clades, innate immune
1722 cells, like uNK cells, may be sufficient to regulate immune responses during pregnancy (Moffett
1723 & Loke, 2004; Chaouat, 2016). Given that there is an unclear distinction between the innate and
1724 adaptive immune system in reptiles (Zimmerman, 2020), determining immunological difficulty
1725 of evolving viviparity in squamates requires further investigation.

1726 In uterine tissue of oviparous and viviparous skinks maternal antigens are expressed prior to
1727 and during gestation and gravidity (Murphy et al., 2009), but the viviparous species in the study
1728 have a unique expression profile of MHC antigens which may ‘hide’ the embryo from the
1729 maternal immune system (Murphy et al., 2009). Similarly, in a reproductively bimodal skink,
1730 *Saiphos equalis*, both oviparous and viviparous gestation is associated with expression of MHC
1731 genes (Foster et al., 2020). Regardless of parity mode, *S. equalis* expresses genes associated with
1732 immunocompetence, including MHC genes including *H2-EA* (Foster et al., 2020). The similar
1733 profile between the oviparous and viviparous state is attributed to the use of very long egg
1734 retention utilized by oviparous *S. equalis* (Foster et al., 2020). This highlights that extended
1735 embryonic retention is accompanied with immunological responses in utero, which is relevant to
1736 the EER model on amniote origins.

1737 Some of these genes expressed by *S. equalis* are also expressed in viviparous *Chalcides*
1738 *ocellatus* during gestation including complement component genes (C3, C9) and MHC genes
1739 (Brandley et al., 2012; Foster et al., 2020). The majority of immune genes expressed during
1740 gestation/gravidity in *S. equalis* have immunoglobulin receptor binding functions (Foster et al.,
1741 2020), an important feature of eutherian pregnancy that prevents rejection of the fetus through
1742 actions of the maternal innate immune system (Alijotas-Reig, Llurba, Gris, 2014)). In another
1743 reproductively bimodal skink, *Zootoca vivipara*, immune system response genes are enriched in
1744 the set of genes under divergent selection in oviparous and viviparous genomes (Recknagel et al.,
1745 2021a).

1746

1747 (4) *Implications of the reptilian immune system and morphology on parity mode evolution*

1748 Ectothermic reptiles may inherently have a more tolerogenic uterine environment compared
1749 to mammals due to their slower antibody response. It can take up to six weeks to reach peak
1750 concentrations (Ingram & Molyneux, 1983; Grey, 1963; Marchalonis et al., 1969; Pye et al.,
1751 2001; Origgi et al., 2001; Work et al., 2000). A slower metabolism also makes several reptiles
1752 more tolerogenic to pathogens (Ghorai & Priyam, 2018).

1753 During pregnancy in the viviparous skink, *Chalcides ocellatus*, there is a reduced response to
1754 in vitro exposure to mitogens concanavalin A (Con A), phytohemagglutinin (PHA), and
1755 *Escherichia coli* lipopolysaccharide (LPS) (Saad & El Deeb, 1990). Oviparous lizards exhibit
1756 immune activation tradeoffs during reproductive cycles (Cox, Peadar, & Cox, 2015; Durso &
1757 French, 2018; French, Johnston, & Moore, 2007; Uller, Isaksson, & Olsson, 2006).

1758 In the majority of viviparous squamates, the eggshell membrane is absorbed during
1759 pregnancy (Blackburn, 1993). In mammals, epitheliochorial placentation (the most superficial
1760 and non-invasive placenta type) is sufficient to cause immunorecognition from the mother.
1761 Specialized placental cells, trophoblasts, may be more common in other viviparous vertebrates
1762 than previously recognized (Blackburn, 2015a). For example, a gene with fusogenic properties
1763 characteristics of trophoblast syncytins was recently identified in the *Mabuya* lizard placenta
1764 (Cornelis et al, 2017). In mammals, trophoblasts are antigen presenting and actively participate
1765 in maternal-fetal immune dynamics.

1766 A few viviparous squamates have placentas with characteristics similar to placentas found in
1767 eutherian mammals—syncytialized cells layers, specialized zones such as areolae and
1768 placentomes, or cellular invasion of maternal tissues by the fetus (Blackburn & Flemming, 2012;
1769 Jerez & Ramírez-Pinilla, 2001; Vieira et al., 2007). The increased contact here may require more

1770 tightly regulated immune dynamics at the maternal-fetal interface compared to other viviparous
1771 squamates.

1772

1773 (5) *The inflammation paradox*

1774 In mammals, implantation evolved from an ancestral inflammatory attachment reaction
1775 (Griffith, Chavan et al., 2017). Inflammation is the most crucial system to support implantation,
1776 but it is also the greatest threat to the continuation of pregnancy (Chavan et al., 2017). This
1777 phenomenon is called the inflammation paradox. In humans, immune cells including uterine
1778 macrophages, T cells of multiple subtypes, uterine natural killer (uNK) cells, dendritic cells, and
1779 natural killer T (NKT) cells increase until implantation and remain abundant in the uterus
1780 throughout first trimester (Bulmer et al., 1991; Bulmer, Williams & Lash, 2010). Early
1781 implantation in humans is characterized by high pro-inflammatory T helper (Th)-1 cells and
1782 cytokines (IL-6, IL-8, and TNF α) (Yoshinaga, 2008). The exploitation of inflammatory
1783 mechanisms for eutherian implantation and the shift toward non-inflammatory activity to
1784 maintain pregnancy may have been key in enabling extended embryonic retention of eutherians
1785 (Griffith, Chavan et al., 2017).

1786 How the inflammation paradox applies to viviparous squamates is unclear, given that
1787 placentation in squamates and mammals is not homologous (Griffith, Van Dyke, & Thompson,
1788 2013). In extrauterine pregnancies of mammals with non-invasive placentas, the embryo will
1789 invade extrauterine tissue because it is not inhibited by uterine secretions (Vogel, 2005; Samuel
1790 & Perry, 1972). However, in *Pseudemoia entrecasteauxii*, a viviparous skink that also has a non-
1791 invasive placenta, extrauterine pregnancy does not result in invasive implantation of extrauterine
1792 tissues (Griffith, Van Dyke, & Thompson, 2013). The inherent invasive nature of mammalian

1793 embryos outside of the uterus, compared to the non-invasive nature of viviparous squamate
1794 embryos studied thus far, suggests that the parent-offspring conflict and the inflammation
1795 paradox may be less pronounced in viviparous squamates compared to viviparous mammals.

1796

1797 *(6) Inertness and barriers at the maternal-fetal interface*

1798 The uterine environment is not inert or sterile (Agostinis et al., 2019; Erlebacher, 2013;
1799 Moffett & Loke, 2006; Munoz-Suano, Hamilton, & Betz, 2011; Murphy, Thompson, & Belov,
1800 2009; Yoshimura, Okamoto, & Tamura, 1997). In humans, the decidual layer of the uterus
1801 during pregnancy is comprised of ~40% leukocytes (Ander, Diamond, & Coyne, 2019; Manaster
1802 & Mandelboim, 2010). This cellular subpopulation has 70% uNK cells, 10-20% antigen
1803 presenting cells (APCs) including macrophages and dendritic cells, and 3-10% T cells of several
1804 subtypes (Abrahams et al., 2004; Hanna et al., 2006; Kämmerer et al., 2006; Le Bouteiller &
1805 Piccinni, 2008; Liu et al., 2017; Manaster & Mandelboim, 2010; Moffett-King, 2002; Moffett &
1806 Loke, 2006; Roussev et al., 2008). There is an abundance of decidual large granular lymphocytes
1807 (LGLs), CD3-NK cells and CD3+ activated cytotoxic T cells, in the human uterus, that have
1808 cytotoxic properties and produce cytokines, and these are affected by fetal MHC molecules
1809 (Rieger, 2002).

1810 Birds also have immunocompetent cells in their oviducts. T and B cells are present in
1811 chicken ovary where they are stimulated by estrogen (Barua & Yoshimura, 1999; Withanage et
1812 al., 2003; Zettergren & Cutlan, 1992). Other immunocompetent cells in the chicken oviduct
1813 include IgG+, IgA+ and CD3+ (Yoshimura, Okamoto, & Tamura, 1997). Immune competent
1814 cells located throughout the mucosal tissue of avian oviductal segments including macrophages,

1815 antigen presenting cells (APCs) expressing MHC class II antigens, helper T cells and cytotoxic T
1816 cells, and premature B cells (Das, Isobe, & Yoshimura, 2008).

1817 Inert barriers between maternal and fetal tissues may 'hide' the embryo. In oviparous taxa,
1818 the eggshell may serve as a barrier. However, the antimicrobial properties of the eggshell matrix
1819 in birds demonstrate that even the eggshell is not inert. The FAS ligand, also called APO-1 or
1820 CD95, in humans and rodent embryonic tissue was proposed to serve as a barrier because it
1821 causes apoptosis of surrounding maternal immune cells (Kayisli et al., 2003; Makrigiannakis et
1822 al., 2008).

1823 Medawar suggested that an impermeable placenta strictly regulates molecular exchanges,
1824 preventing rejection of the embryo (Medawar, 1991). Syncytiotrophoblasts lack cellular junctions
1825 and thus it was postulated to serve as this barrier (Ander et al., 2019). However, the growing data
1826 on bidirectional cellular traffic of APCs, even in mammals with noninvasive placentas, rejected
1827 this hypothesis (Bakkour et al., 2014; Burlingham & Bracamonte-Baran, 2015; Fujiki et al.,
1828 2008; Turin et al., 2007).

1829

1830 (7) *T cell populations and mammalian viviparity*

1831 In mammals, immune-dynamics at the maternal-fetal interface are established through
1832 innate and adaptive immune responses. There is a delicate balance between ratios of Th1, Th2,
1833 Th17, Tregs and memory T cells at the maternal-fetal interface in eutherian mammals during
1834 gestation (Chaouat et al., 1997; Kieffer et al., 2019; Peck & Mellins, 2010; Saito et al., 2010; Wu
1835 et al., 2014). A shift in utero from T helper type 1 (Th1) cells to T helper type 2 (Th2) cells
1836 during gestation in mammals equates to a shift from pro-inflammation to anti-inflammation. The
1837 galectin proteins, GAL-13 and GAL-14, expressed by syncytiotrophoblasts, bind to T cells

1838 where they inhibit activation, induce apoptosis, and enhance interleukin-8 (IL-8) production
1839 (Balogh et al., 2019).

1840 Growing research is revealing the central role of Tregs at the maternal-fetal interface
1841 during pregnancy in mammals (Teles et al., 2013; Wienke et al., 2019). Tregs play a central role
1842 in immunosuppression in mammals (Attias, Al-Aubodah, & Piccirillo, 2019). Differentiation of
1843 Tregs is governed by the transcription factor, *FOXP3* (Ramsdell & Rudensky, 2020).
1844 Alloantigen-dependent, uterine T cell signaling, and immunocompetent embryonic cells and their
1845 products facilitate enhanced regulatory phenotypes of immune cells overall (Ander et al., 2019).

1846 The T-cell dependent adaptive immune system of mammals is unique. This may have
1847 prompted their intricate balance of Treg mediators of immunotolerance at the maternal-fetal
1848 interface (Chaouat, 2016). Birds rely more heavily on B cells. In non-avian reptiles, T helper
1849 cells are functional, but the presence and function of other T cell subsets is unclear (Zimmerman,
1850 2020; Zimmerman, Vogel, & Bowden, 2010). The potential role of T cells and Tregs in
1851 viviparous squamate gestation should not be discounted. Treg-like cells have been identified in a
1852 pufferfish, *Tetraodon nigroviridis* (Wen et al., 2011), suggesting that Tregs may have an ancient
1853 evolutionary history.

1854

1855 (8) *Progesterone, cytokines, and maternal-fetal immune dynamics*

1856 In addition to the role of progesterone in uterine quiescence (embryonic retention) and
1857 hepatic vitellogenesis (nutrient provisioning), it also plays a role in maternal-fetal immune
1858 dynamics. In the uterus of pregnant mammals, progesterone concentrations are associated with
1859 altered B cell immunoglobulin secretion, inhibition of NK-cell mediated cytotoxicity and the shift
1860 from Th1 (pro-inflammatory) to Th2 (anti-inflammatory) dominated immune responses

1861 (Druckmann & Druckmann, 2005). Progesterone is also associated with immunomodulatory
1862 effects (Ortega Brown et al., 1990). During gestation in *Agkistrodon piscivorus*, a viviparous pit
1863 viper, progesterone concentrations are associated with decreased complement performance
1864 (Graham et al., 2011), a portion of the immune system that promotes inflammation, among other
1865 immune functions.

1866 In humans, progesterone induced protein (PIBF) is transported by placental extravillous
1867 trophoblasts to maternal lymphocytes causing the induction of interleukin-10 (IL-10) production,
1868 contributing to the Th2 dominant responses (Szekeres-Bartho, Šučurović, & Mulac-Jeričević,
1869 2018). IL-10 is a potent anti-inflammatory cytokine that is produced by multiple cell types
1870 (Zimmerman, Bowden, & Vogel, 2014). It is associated with Th2 response, and it inhibits Th1
1871 responses. The phenotype of uterine macrophages is affected by trophoblasts when they secrete
1872 IL-10 and macrophage colony-stimulating factor (M-CSF) (Svensson-Arvelund et al., 2021). IL-
1873 10 inhibits IFN- γ and increases in response to infection in chickens (Giansanti, Giardi, & Botti,
1874 2006; Rothwell et al. 2004). In the uterus of the oviparous skink, *Lampropholis guichenoti*,
1875 during gravidity and non-gravidity, IL-10 is expressed (Griffith et al., 2016).

1876 Proinflammatory cytokines may be downregulated during reproductive periods to limit
1877 maladaptive immune responses to the foreign fetus (Zimmerman, Vogel, & Bowden, 2010). In
1878 mammals, IL-1 allows release of hormones in human trophoblasts (Petraglia et al., 1990;
1879 Masuhiro et al., 1990; Yagel et al., 1989), facilitates implantation (Haimovici, Hill, & Anderson,
1880 1991; Hill, 1992; Tartakovsky & Ben-Yair, 1991), and influences the initiation of labor (Romero
1881 et al., 1989, 1992). Regulation of the proinflammatory cytokines tumor necrosis factor (TNF)
1882 and interleukin 1B (IL-1 β) is of particular importance in eutherian pregnancy (Haider & Knöfler,
1883 2009; Paulesu, Romagnoli, & Bigliardi, 2005; Saito et al., 2010; Tayade et al., 2006).

1884 The uterine tissue of two reproductively bimodal squamates—viviparous individuals of
1885 *Chalcides chalcides*, and oviparous and viviparous individuals of *Zootoca vivipara*—express IL-
1886 1 β (Paulesu et al., 1995, 2005; Romagnoli et al., 2003). In the uterus of the viviparous skink,
1887 *Pseudemoia entrecasteauxii*, during gestation regulation of TNF and IL-1 β at the transcriptional
1888 and post-translation levels, respectively, may reduce inflammation (Hendrawan et al., 2017). The
1889 pro-inflammatory function of IL-1 β in *Pseudemoia entrecasteauxii* may play a role developing a
1890 more complex placenta (Hendrawan et al., 2017). The placenta of *Chalcides chalcides* expresses
1891 pro-inflammatory cytokines, IL-1 α and IL-1 β , at specific times during gestation (Paulesu et al.,
1892 1995). During gestation, *Chalcides ocellatus* also differentially expresses 27 other interleukins
1893 and interleukin related products (Brandley et al., 2012).

1894 The expression of IL-34 in a marsupial, the fat-tailed dunnart, during pre-implantation
1895 (Whittington et al., 2018) may have an immunosuppressive function to help tolerate potential
1896 contact of maternal and fetal tissues when the embryonic shell coat disintegrates (Lindau et al.,
1897 2015). In chickens, IL-34 regulates Th1 and Th17 cytokine production (Truong et al., 2018).
1898 During gestation in *Pseudemoia entrecasteauxii*, IL-16 and IL-1 α are expressed in addition to
1899 three receptors for Th17 family cytokines—IL-17RA, IL-17RC, and IL-17RA (Griffith,
1900 Brandley, et al., 2016, 2017). In the yolk sac of *Pseudemoia entrecasteauxii* during pregnancy
1901 interleukin related molecules, *ILDR1*, *IRAK1*, and *SIGIRR*, are differentially expressed (Griffith
1902 et al., 2016). This profile suggests the presence of tricellular tight junctions and/or tricellulin
1903 (Higashi et al., 2013; Ikenouchi et al., 2005), and regulation of toll-like receptors (TLRs) and/or
1904 IL-1R signaling (Kawagoe et al., 2008; Lin, Lo, & Wu, 2010; Muzio et al., 1997).

1905

1906 (9) *The major histocompatibility complex and maternal-fetal immune dynamics*

1907 A substantial amount of literature on maternal-fetal immune dynamics was focuses on uNK
1908 cells. Uterine NK cells have a distinct phenotype and function from peripheral NK cells. They
1909 have several activating receptors (Manaster & Mandelboim, 2010) but do not exert cytolytic
1910 functions on embryonic trophoblasts that they are in contact with (King, Birkby, & Loke, 1989).
1911 Allorecognition of embryonic placental cells by uNK cells is a key regulator of the maternal-fetal
1912 immune mechanisms that support placentation in mammals (Moffett & Colucci, 2014). When
1913 cells lose their ability to express any HLAs, uNK cells are shown to kill them (Hunt et al., 2005;
1914 Ishitani et al., 2003; King, Allen et al., 2000).

1915 In humans, expression of the classical MHC class I (C-MHCI) molecule HLA-C, and
1916 nonclassical MHC class I (NC-MHCI) molecules HLA-E, HLA-F and HLA-G on trophoblasts
1917 inhibit uNK cell-mediated cytotoxicity (Hunt et al., 2003; King, Burrows et al., 2000). Differing
1918 from this, mismatched HLA-C profiles trigger rejection of the transplanted organs (Petersdorf et
1919 al., 2014). Selection for balanced polymorphisms in HLA-C alleles and their killer
1920 immunoglobulin receptors (KIRs) is proposed to be driven by reproductive success, rather than
1921 immune recognition of pathogens (Trowsdale & Betz, 2006). Dimorphisms of HLA-C emerged
1922 recently within primates (Adams & Parham, 2001).

1923 Similar patterns in MHC profiles have been explored in other viviparous amniotes. C-MHCI
1924 antigen, H2-K, is expressed on giant trophoblast cells of mice and this is attributed to
1925 trophoblast-induced uterine vasculature transformation (Arcellana-Panlilio & Schultz, 1994;
1926 Chatterjee-Hasrouni & Lala, 1982; Hedley et al., 1989; King et al., 1987; Sellens, Jenkinson, &
1927 Billington, 1978). H2-D antigen is co-expressed with H2-K in virtually all their other nucleated
1928 cells (Madeja et al., 2011). However, H2-K expressing trophoblasts lack H2-D expression. This

1929 parallels the expression patterns of C-MHC molecules at the maternal-fetal interface in humans
1930 and may be an evolutionarily conserved pattern (Madeja et al., 2011).

1931 In humans, NC-MHCI molecule, HLA-G, is especially tolerogenic (Carosella et al., 2015;
1932 González et al., 2012; Hviid et al., 2004; Kovats et al., 1990). In adults, HLA-G is almost
1933 exclusively expressed by fetal trophoblasts compared to adult cells (Faulk & Temple, 1976;
1934 King, Burrows et al., 2000; Kovats et al., 1990; Rajagopalan & Long, 2012; Rouas-Freiss et al.,
1935 1997). It supports immunotolerance at the maternal-fetal interface (Rebmann et al., 2014). The
1936 role of HLA-G in supporting tolerogenic responses to organ transplants appears to be an
1937 exploitation of its role in immunotolerance in the utero during pregnancy (Rebmann et al., 2014).
1938 HLA-G is upregulated by several molecules that serve essential roles during gestation including
1939 progesterone (Yie, Xiao, & Librach, 2006; Yie et al., 2006), IFN- α , IFN- β , and IFN- γ (Rebmann
1940 et al. 2003; Lefebvre et al., 2001; Ugurel et al., 2001; Yang, Geraghty, & Hunt, 1995), and IL-10
1941 and TGF- β (Cadet et al., 1995; Moreau et al., 1999).

1942 A similar NC-MHCI gene to HLA-G exists in horses (Davies et al., 2006) where it likely
1943 functions to protect the embryo from NK-cell mediated attack (Ott et al., 2014). NC-MHC
1944 molecules with similar structure to HLA-G are also found in Rhesus monkeys (Boyson et al.,
1945 1997) and baboons (Stern et al. 1987). Mice have two NC-MHCI genes that are expressed on the
1946 surface of their placentas and on pre-implanted embryos (Sipes et al., 1996).

1947 In the gestating uterus of the viviparous skink, *Pseudemoia entrecasteauxii*, four putative C-
1948 MHCI and two putative NC-MHCI molecules are expressed (Murphy, Thompson, & Belov,
1949 2009). This pattern resembles the C-MHCI and NC-MHCI expression profiles of mammals,
1950 suggesting that this viviparous skink utilizes a similar physiological mechanism to 'hide' the
1951 embryo (Murphy, Thompson, & Belov, 2009). One of the putative NC-MHCI genes (Psen-

1952 160Ut/Psen-78G) has a substitution at position 150 where a tryptophan is substituted for a
1953 leucine (Murphy, Thompson, & Belov, 2009). When Psen-160Ut/Psen-78G was aligned to NC-
1954 MHC I genes of vertebrates ranging from fish to eutherian mammals, tryptophan was conserved
1955 at position 150 except in Psen-160Ut/Psen-78G and HLA-G (Murphy, Thompson, & Belov,
1956 2009). Whether this reflects an evolutionary history associated with immune tolerance at the
1957 maternal-fetal interface in *Pseudemoia entrecasteauxii* requires further investigation.

1958 MHC I genes are also expressed in reproductive tissues of oviparous skinks (*Ctenotus*
1959 *taeniolatus* and *Lampropholis guichenoti*) during non-reproductive periods and during late
1960 gravidity (Murphy, Thompson, & Belov, 2009). A similar pattern is found in viviparous skinks
1961 *Eulamprus tympanum*, *Niveoscincus metallicus*, *Pseudemoia entrecasteauxii* and the
1962 reproductively bimodal skink *Saiphos equalis* which all express MHC I genes at non-
1963 reproductive periods and during late pregnancy/gravidity (Murphy, Thompson, & Belov, 2009).
1964 MHC gene H2-EA is also expressed during gestation with long egg retention in *Saiphos equalis*.

1965 The butyrophilin subfamily 1 member A (*BTN1A1*) is located in the MHC I region of the
1966 genome in mammals (Trowsdale, 2011). *BTN1A1* is differentially expressed in the uterus during
1967 gestation in a viviparous lizard, *Chalcides ocellatus* (Brandley et al., 2012). *BTN1A1* may have
1968 important antimicrobial properties in chicken eggshells (Mann, Maček, & Olsen, 2006). In
1969 mammals *BTN1A1* is the major protein associated with fat droplets in milk (Jeong et al., 2009).

1970

1971 (10) *Microchimerism and maternal-fetal immune dynamics*

1972 Billingham, Brent and Medawar suggested the concept of actively acquired immunologic
1973 tolerance during pregnancy 70 years ago (Billingham, Brent, & Medawar, 1953; Ribatti, 2015).
1974 Subsequent research over the following decades revealed that substantial transfer of proteins,

1975 parasites and even immunologically active cells occurs between mother and embryo (Adams &
1976 Nelson, 2004; Axiak-Bechtel et al., 2013; Bakkour et al., 2014; Burlingham, 2010; Fujiki et al.,
1977 2008; Gitlin et al., 1965; Khosrotehrani et al., 2005; Owen, 1945; Turin et al., 2007).
1978 Microchimerism, where there is <0.1% donor chimeras in host tissue, is relatively pervasive
1979 among eutherians during pregnancy. It plays a role in establishing tolerance to non-inherited
1980 antigens. For example, cell populations from the mother that are transferred into embryonic
1981 lymph nodes enable the establishment of embryonic Tregs that are tolerogenic toward non-
1982 inherited maternal antigens (Mold et al., 2008).

1983 Microchimeric cellular populations are transferred across all placental types (Axiak-Bechtel
1984 et al., 2013; Bakkour et al., 2014; Fujiki et al., 2008; Khosrotehrani et al., 2005; Turin et al.,
1985 2007). Fetal and maternal cells persist for decades after birth across a range of tissues in mother
1986 and offspring, respectively (Adams & Nelson, 2004; Bakkour et al., 2014; Bayes-Genis et al.,
1987 2005; Bianchi et al., 1996; Evans et al., 1999; Jonsson et al., 2008; Stevens et al., 2004). There is
1988 even a call in the immunology literature to shift from the conventional paradigm of “self vs
1989 other” to instead consider the “self” as inherently chimeric (Nelson, 2012). Given that
1990 epitheliochorial placentation is sufficient to illicit microchimeric cell populations, the occurrence
1991 of similar bidirectional cellular traffic is a reasonable possibility in viviparous squamates.

1992

1993 (11) *Paternal alloantigens*

1994 Under tenants gleaned from transplant medicine, the maternal immune system would illicit
1995 an attack response as early as insemination when maternal tissues are exposed to paternal
1996 alloantigens (Borziak et al., 2016; Schumacher & Zenclussen, 2015; Seavey & Mosmann, 2006).
1997 Instead, maternal cells immunologically recognize them at this time without attack (Schumacher

1998 & Zenclussen, 2015; Seavey & Mosmann, 2006; Zenclussen et al., 2010). Treg expansion, a
1999 process with major influence on maternal-fetal immunotolerance in mammals, is proposed to be
2000 driven by several different factors found in seminal plasma (Baratelli et al., 2005; Teles et al.,
2001 2013). Mothers may maintain fetal-specific Tregs with memory of the paternal alloantigens
2002 (Zenclussen et al., 2010), expediting Treg response in future pregnancies with the same father
2003 (Rowe et al., 2012).

2004 Alloantigen exposure at the time of insemination is not restricted to mammals. Seminal fluid
2005 of chickens contains two MHC I paternal alloantigens and one MHC II alloantigen (Borziak et
2006 al., 2016). It also contains proteins involved in immunity and antimicrobial defenses (Borziak et
2007 al., 2016). In hens, evidence suggests that a protective local immunity to pathogens is established
2008 after exposure to semen but the mechanisms for this remain unclear (Reiber & Conner, 1995;
2009 Reiber, Conner, & Bilgili, 1995).

2010 In mammals, paternal alloantigens and cytokines in seminal fluid drive immune tolerance
2011 (Schjenken & Robertson, 2014). Mammalian seminal plasma contains immune-factors (Kelly,
2012 1995; Schjenken & Robertson, 2014)—TGF- β (Breuss et al., 1993; Chu & Kawinski, 1998;
2013 Slater & Murphy, 1999), IL-8 (Gutsche et al., 2003), and soluble IL-2 receptor (Srivastava,
2014 Lippes, & Srivastava, 1996), prostaglandin E2 (PGE2) and 19-hydroxyprostaglandin E (19-
2015 hydroxy PGE) (Denison et al., 1999), soluble tumor necrosis factor (TNF) receptors (Liabakk et
2016 al., 1993), receptors for the Fc portion of γ -globulin, spermine (Evans, Lee, & Flugelman, 1995),
2017 and complement inhibitors (Kelly, 1995). In horses and pigs, respectively, the proteins CRISP3
2018 (Doty et al., 2011), PSP-I and PSP-II (Rodriguez-Martinez et al., 2010), act as signaling agents
2019 in seminal fluid.

2020 Secretions of growth factors, cytokines and chemokines from cervical and endometrial
2021 tissues immediately following insemination generates a proinflammatory environment that likely
2022 aids in implantation. In the utero-vaginal junction of chickens and the utero-tubal junction of
2023 pigs, expression of several genes were shared following mating compared to non-mating and
2024 these genes were involved with immune-modulation (*IFIT5*, *IFI16*, *MMP27*, *ADAMTS3*, *MMP3*,
2025 *MMP12*) and pH-regulation (*SLC16A2*, *SLC4A9*, *SLC13A1*, *SLC35F1*, *ATP8B3*, *ATP13A3*), a
2026 process essential for implantation (Atikuzzaman et al., 2017, 2015). Instead of mounting an
2027 attack, it appears that the uterine immune system and paternal genes work cooperatively to
2028 support pregnancy in mammals and gravidity in birds. Whether this applies to reptiles, and how
2029 it may influence immune dynamics involved with squamate parity mode evolution, deserves
2030 investigation.

2031

2032 (12) *Discussion and future directions—maternal-fetal immune dynamics & the*
2033 *evolution of parity modes*

2034 Immune processes appear to be important for both oviparity and viviparity—as evidenced
2035 here, in part, by overlapping expression profiles of immune genes in female reproductive tissues
2036 of chickens and pigs, expression of paternal antigens in avian seminal fluid, and uterine
2037 expression of maternal antigens in oviparous and viviparous skinks. This highlights the scientific
2038 advances made since Medawar’s paradigm, when embryos were treated as analogs to allografts.
2039 Nonetheless, viviparity is associated with complex immune dynamics between maternal, fetal,
2040 and paternal tissues.

2041 Overall, evolving appropriate immunological responses is one hurdle of transitions to
2042 viviparity in squamates. This is evidenced by the unique MHC expression profiles identified in

2043 some viviparous skinks compared to oviparous relatives (Murphy et al., 2009); and the detection
2044 of divergent selection in immune response genes in viviparous and oviparous *Zootoca vivipara*
2045 (Recknagel et al., 2021a). Labile parity modes in squamates may be supported if they are more
2046 heavily reliant on the innate immune system for reproduction. However, reptiles may not have
2047 distinguished innate and adaptive immune systems (Zimmerman et al., 2020).

2048 Changes to genes that serve overlapping functions across the Main Five may have a
2049 disproportionate influence on transitions between parity modes. In this section I reviewed two
2050 molecules, *TGF-β* and progesterone, that exert influence on multiple Main Five categories.
2051 Progesterone influences uterine quiescence (embryonic retention), hepatic vitellogenesis
2052 (nutrient provisioning) and regulation of inflammatory responses in utero (maternal-fetal
2053 immune dynamics). Genes in the *TGF-β* family play a role in placental development and
2054 maternal-fetal immune dynamics. *TGF-β* family is implicated in placental development in
2055 eutherians (Hempstock et al., 2004; Caniggia et al., 2000; Lafontaine et al., 2011). A *TGF-β*
2056 receptor protein (*TGFBR1*) was associated with placental development in *Phrynocephalus*
2057 *vlangalii* (Gao et al., 2019). In humans *TGF-β* upregulates tolerogenic HLA-G in utero and is an
2058 immune factor in mammalian seminal fluid. Multiple genes in the *TGF-β* family are also
2059 differentially expressed during gestation in other viviparous lizards, *Pseudemoia entrecasteauxii*
2060 and *Saiphos equalis* (Foster et al., 2020; Griffith et al., 2016). Examining the functions of *TGF-β*
2061 and progesterone across other amniotes may reveal insights into how these molecules influence
2062 the evolution of parity modes.

2063 In mammals, inflammation appears to be involved with two of the Main Five processes—
2064 regulation of maternal-fetal immune dynamics and embryonic retention. It is intriguing to
2065 consider the implications this has for the interconnectedness of the Main Five. Greater

2066 interconnectedness would suggest that changes to few genes involved with the Main Five could
2067 cause a cascading effect to support more labile transitions between parity modes.

2068 Implantation and parturition in therian mammals evolved from a shared inflammatory
2069 attachment reaction (Hansen et al., 2017). The process of implantation has important
2070 implications for maternal-fetal exchanges of inorganic and organic material and maternal-fetal
2071 immune dynamics. Given that inflammation is associated with implantation and parturition
2072 implicates it in gas, water, and nutrient provisioning (including calcium here), maternal-fetal
2073 immune dynamics and length of embryonic retention. However, implantation in mammals and
2074 viviparous squamates is not homologous (Griffith, Van Dyke, & Thompson, 2013). Therefore, it
2075 is difficult to make inferences about how substantial the influence of inflammation is on the
2076 evolution of parity modes in squamates. Nonetheless, the abundant literature on uterine
2077 inflammatory processes during human pregnancy and the evolution of inflammatory processes
2078 that supported the evolution of viviparity in mammals (Challis et al., 2009; Chavan, Griffith, &
2079 Wagner, 2017; Mor et al., 2011; Griffith, Chavan et al., 2017; Stadtmauer & Wagner, 2020a)
2080 serve as indispensable resources for exploring the role of inflammation in squamate viviparity. I
2081 resist expanding on this further. I suspect that the immune system plays a central role in dictating
2082 the plasticity of parity modes. However, further work is necessary to validate this.

2083

2084

2085 **VII. Conclusions**

2086

2087 (1) Through holistic consideration of the unique complexity of parity mode evolution, within
2088 the context of genomic and transcriptomic studies across interdisciplinary fields, this

2089 review provided a new perspective on the history of parity mode transitions in amniotes
2090 and squamates. The overlapping activity of immune genes in utero, genes for calcium
2091 transport, placentation, and hormonal regulation across mammals, birds, and reptiles hint
2092 at discoveries to be made. There is a fascinating history to the evolutionary physiology
2093 and genomics of reproduction in amniotes that is ripe for downstream research.

2094 (2) Changes to gene(s) or physiological processes associated with more than one of the Main
2095 Five should disproportionately influence parity mode evolution—*SLC* gene superfamily,
2096 TGF- β , *BMPRI1B*, progesterone, *PMCA*, calbindin-D28K, *SPP1*, sustained functioning of
2097 the corpora lutea and inflammation, and the genes associated with both gestation length
2098 and eggshell traits in *Zootoca vivipara* (Recknagel et al., 2021a).

2099 (3) Growing evidence in the medical literature suggests that immune system interactions at
2100 the maternal-fetal interface in mammals did not evolve simply through immunotolerance,
2101 evasion, immunosuppression, or immunological barriers (Chaouat, 2016; Chavan,
2102 Griffith, & Wagner, 2017; Moffett & Loke, 2004, 2006). Instead, maternal-fetal immune
2103 dynamics have a deep evolutionary history that enables both embryo and mother to
2104 interact cooperatively (Yoshizawa, 2016). Viviparity and extended embryonic retention
2105 are assuredly associated with immunological responses across amniotes, including
2106 squamates (e.g. Foster et al., 2020). Oviparous birds and squamates are also known to
2107 differentially express genes during gravidity, with one exception to my knowledge,
2108 *Lampropholis guichenoti* (Griffith et al., 2016).

2109 (4) Compared to viviparous endothermic amniotes, ectothermy likely influences parity mode
2110 evolution differently because it entails slower antibody responses and a greater reliance
2111 on climatic conditions for embryonic development. This and the Cold Climate

2112 Hypothesis are likely relevant to the origin of the amniotic egg and squamate parity mode
2113 evolution. Climatic shifts during the origin of amniotes should be explored for their
2114 consistency with the EER model.

2115 (5) Two new mechanisms for transitions between oviparity and viviparity, without
2116 necessitating intermediate stages, stand out from the cumulative research on the Main
2117 Five. These are presented here (Conclusions 6 and 7) as tools to be broadened and
2118 challenged with the goal of advancing scientific insight on the subject.

2119 (6) The genomics and physiology of amniote parity mode evolution does not preclude an
2120 origin of viviparity in the MRCA of Lepidosauria. I propose the following mechanism—a
2121 change to the phenotype or function of mammillary knobs occurred in the MRCA of
2122 Lepidosauria, instantaneously preventing calcium carbonate deposition (basal cap
2123 hypothesis); the eggshell loss enabled uterine exposure to chorioallantoic progesterone
2124 production (extending embryonic retention) and incipient calcium matrotrophy
2125 (supporting embryonic development); parturition occurred via 1) placental progesterone
2126 withdrawal or 2) overdistension of the uterus triggers contractions. This is one way to
2127 imagine viviparity evolving in the MRCA of Lepidosauria.

2128 a. Hypothesis testing: If the genes that code for the KS-proteoglycan, “mammillan”,
2129 that makes up mammillary knobs are absent or non-functional across squamates
2130 and tuatara, then this would support the basal cap hypothesis. To test this
2131 hypothesis, the genes must be identified in Archelosaur genomes and proteomes.
2132 Additionally, ancestral state reconstructions on the eggshell and eggshell
2133 membrane should be generated across oviparous and viviparous Archelosaurs,
2134 utilizing current recommendations for characterizing eggshell microstructure

2135 (Legendre et al., 2022). This will require also developing a system to accurately
2136 characterize eggshell membranes.

2137 (7) The calcium secreting capacity of the uterus is maintained in oviparous and viviparous
2138 squamates. Therefore, a reversal back to oviparity may evolve through the following
2139 sequence of events—calcium secretions in utero stick to the eggshell membrane instead
2140 of being absorbed by the chorioallantois; oviposition can then occur early in embryonic
2141 development in one of two ways 1) the death of corpora lutea or 2) the calcified eggshell
2142 blocks a threshold of chorioallantoic progesterone production from reaching uterine
2143 tissue; the calcified eggshell then provides embryonic calcium that is transported upon
2144 embryonic metabolic demand.

2145 a. Hypothesis testing: Recent reversals should have physiological or genomic
2146 remnants of a viviparous past. Given that viviparous squamates generally have
2147 more active uterine immune systems to support gestation, oviparous reversals
2148 should 1) have more immune genes expressed in utero than ancestrally oviparous
2149 squamates, and 2) these immune genes should have stronger signatures of relaxed
2150 selection than immune genes expressed in a close relative during viviparous
2151 gestation.

2152 (8) Throughout this review, I highlighted the immunological problem of pregnancy by
2153 examining evidence for Medawar's Paradigm across birds, reptiles, and mammals. In
2154 doing so, I identified only one species that does not differentially express any genes while
2155 the egg is in utero, *Lampropholis guichenoti* (Griffith et al., 2016). Given that an
2156 immunological response to gravidity is evidenced in birds and multiple oviparous

2157 squamates, we can understand that *L. guichenoti* either achieves gestation through tenants
2158 of Medawar's Paradigm or that gravidity is not an immunological problem in this species.
2159 (9) I also demonstrated how Medawar's Paradigm is not a good explanation for viviparous or
2160 oviparous gestation/gravidity in amniotes. Some work also suggests that viviparity in
2161 anamniotes causes no immunological problems (Chaouat, 2016). Therefore, I
2162 conceptualize amniotes as originating in an immunological environment that tolerated
2163 exposure to the egg without an immunological issue. I suggest researchers utilize
2164 *Lampropholis guichenoti* as a model for the origin of the amniote egg. If supported by
2165 future research, then oviparous populations of *Saiphos equalis* and *Zootoca vivipara* may
2166 represent reversals because they have substantial differential gene expression during
2167 gravidity (Foster et al., 2020; Recknagel et al., 2021) and the oviparous population of
2168 *Lerista bougainvillii*, which has only two differentially expressed genes during gravidity,
2169 may represent an ancestrally oviparous state (Griffith et al., 2016). Future work can test
2170 this by applying point 7.A in this conclusion and should measure differentially expressed
2171 genes across stages of gravidity in *L. bougainvillii*.

2172 (10) Given that the mammillary layer is described as unique to Archelosaurs, the original
2173 oviparous amniote eggshell may have lacked a mammillary layer. Instead, it makes
2174 logical sense that the original oviparous amniote egg became ensheathed in an eggshell
2175 membrane, followed by calcium deposition that looks comparable to what we see in
2176 squamates. We can test this by using the framework of the basal cap hypothesis,
2177 described briefly in point 6 of this conclusion and at length in section III.3.

2178
2179

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2185 **IX. References**

2186

2187 Abrahams, V. M., Y. Mee Kim, S. L. Straszewski, R. Romero, and G. Mor. (2004).

2188 Macrophages and Apoptotic Cell Clearance during Pregnancy. *American Journal of*

2189 *Reproductive Immunology* **51**(4), 275–82.

2190 Adams, S. M., J. M. Biazik, M. B. Thompson, and C. R. Murphy. (2005). Cyto-Epitheliochorial

2191 Placenta of the Viviparous Lizard *Pseudemoia Entrecasteauxii*: A New Placental

2192 Morphotype *Journal of Morphology* **264**(3), 264–76.

2193 Adams, K. M., and J. L. Nelson. (2004). Microchimerism: An Investigative Frontier in

2194 Autoimmunity and Transplantation. *Journal of the American Medical Association* **291**(9),

2195 1127–31.

2196 Adams, A. P., J. G. Oriol, R. E. Campbell, Y. C. Oppenheim, W. R. Allen, and D. F. Antczak.

2197 (2007). The Effect of Skin Allografting on the Equine Endometrial Cup Reaction.

2198 *Theriogenology* **68**(2), 237–47.

2199 Adams, E. J., and P. Parham. (2001). Species-specific evolution of MHC class I genes in the

2200 higher primates. *Immunological Reviews* **183**, 41-64.

2201 Adams Waldorf, K. M., N. Singh, A. R. Mohan, R. C. Young, L. Ngo, A. Das, J. Tsai, et al.

2202 (2015). Uterine Overdistention Induces Preterm Labor Mediated by Inflammation:

2203 Observations in Pregnant Women and Nonhuman Primates. *American Journal of*

2204 *Obstetrics and Gynecology* **213**(6), 830.E1—830.E19

- 2205 Agostinis, C., A. Mangogna, F. Bossi, G. Ricci, U. Kishore, and R. Bulla. (2019). Uterine
2206 Immunity and Microbiota: A Shifting Paradigm. *Frontiers in Immunology* **10**
- 2207 Albergotti, L. C., and L. J. Guillette. (2011). Viviparity in Reptiles: Evolution and Reproductive
2208 Endocrinology. Hormones and Reproduction of Vertebrates. In D. O. Norris and K. H.
2209 Lopez (Eds.), *Hormones and Reproduction of Vertebrates* (pp. 247-275). Academic
2210 Press.
- 2211 Alföldi, J., F. di Palma, M. Grabherr, C. Williams, L. Kong, E. Mauceli, P. Russell, et al. (2011).
2212 The Genome of the Green Anole Lizard and a Comparative Analysis with Birds and
2213 Mammals. *Nature* **477**(7366), 587–91.
- 2214 Alijotas-Reig, J., Llurba, E., & Gris, J. M. (2014). Potentiating maternal immune tolerance in
2215 pregnancy: a new challenging role for regulatory T cells. *Placenta*, **35**, 241–248.
- 2216 Amoroso, E. C. (1968). The Evolution of Viviparity. *Proceedings of the Royal Society of*
2217 *Medicine* **61**.
- 2218 Ander, S. E., M. S. Diamond, and C. B. Coyne. (2019). Immune Responses at the Maternal-Fetal
2219 Interface. *Science Immunology* **4**(31).
- 2220 Anderson, R. E., C. V. Gay, and H. Schraer. (1981). Ultrastructural Localization of Carbonic
2221 Anhydrase in the Chorioallantoic Membrane by Immunocytochemistry. *Journal of*
2222 *Histochemistry and Cytochemistry* **29**(10), 1121–27.
- 2223 Anderson, D. J., N. C. Stoyan, and R. E. Ricklefs. (1987). Why Are There No Viviparous Birds?
2224 A Comment. *The American Naturalist* **130**(6), 941–47.

- 2225 Andrukhova, O., C. Streicher, U. Zeitz, and R. G. Erben. (2016). Molecular and Cellular
2226 Endocrinology FGF23 and Parathyroid Hormone Signaling Interact in Kidney and Bone.
2227 *Molecular and Cellular Endocrinology* **436**, 224–39.
- 2228 Aoki, R. (1993). The multiple origins of the eggshell in amniote evolution. *Journal of Fossil*
2229 *Research* **27**, 9–43.
- 2230 Arazi, H., I. Yoselewitz, Y. Malka, Y. Kelner, O. Genin, and M. Pines. (2009). Osteopontin and
2231 Calbindin Gene Expression in the Eggshell Gland as Related to Eggshell Abnormalities.
2232 *Poultry Science* **88**(3), 647–53.
- 2233 Arcellana-Panlilio, M. Y., and G. A. Schultz. (1994). Temporal and Spatial Expression of Major
2234 Histocompatibility Complex Class I H-2K in the Early Mouse Embryo. *Biology of*
2235 *Reproduction* **51**(2), 169–83.
- 2236 Arck, P. C., and K. Hecher. (2013). Fetomaternal Immune Cross-Talk and Its Consequences for
2237 Maternal and Offspring’s Health. *Nature Medicine* **19**(5), 548–56.
- 2238 Arenas-Hernandez, M., R. Romero, D. St Louis, S. S. Hassan, E. B. Kaye, and N. Gomez-Lopez.
2239 (2016). An Imbalance between Innate and Adaptive Immune Cells at the Maternal-Fetal
2240 Interface Occurs Prior to Endotoxin-Induced Preterm Birth. *Cellular and Molecular*
2241 *Immunology* **13**(4), 462–73.
- 2242 Arias, J. L., M. Cataldo, M. S. Fernandez, and E. Kessi. (1997). Effect of Beta-
2243 aminopropionitrile on Eggshell Formation. *British Poultry Science* **38**(4), 349–54.

- 2244 Arias, J. L., D. J. Fink, S. Qun Xiao, A. H. Heuer, and A. I. Caplan. (1993). Biomineralization
2245 and Eggshells: Cell-Mediated Acellular Compartments of Mineralized Extracellular
2246 Matrix. *International Review of Cytology* **145**(C), 217–50.
- 2247 Arrowsmith, S., and S. Wray. (2014). Oxytocin: Its Mechanism of Action and Receptor
2248 Signaling in the Myometrium. *Journal of Neuroendocrinology* **26**(6), 356–69.
- 2249 Astheimer, L., and C. R. Grau. (1990). A Comparison of Yolk Growth Rates in Seabird Eggs.
2250 *Ibis* **132**(3), 380–94.
- 2251 Atikuzzaman, M., M. Alvarez-Rodriguez, A. V. Carrillo, M. Johnsson, D. Wright, and H.
2252 Rodriguez-Martinez. (2017). Conserved Gene Expression in Sperm Reservoirs between
2253 Birds and Mammals in Response to Mating. *BMC Genomics* **18**(1).
- 2254 Atikuzzaman, M., R. M. Bhai, J. Fogelholm, D. Wright, and H. Rodriguez-Martinez. (2015).
2255 Mating Induces the Expression of Immune- and PH-Regulatory Genes in the Utero-
2256 Vaginal Junction Containing Mucosal Sperm-Storage Tubuli of Hens. *Reproduction*
2257 **150**(6), 473–83.
- 2258 Attias, M., T. Al-Aubodah, and C. A. Piccirillo. (2019). Mechanisms of Human FoxP3+ Treg
2259 Cell Development and Function in Health and Disease. *Clinical and Experimental*
2260 *Immunology* **197**(1), 36–51.
- 2261 Axiak-Bechtel, S. M., S. R. Kumar, S. A. Hansen, and J. N. Bryan. (2013). Y-Chromosome
2262 DNA Is Present in the Blood of Female Dogs Suggesting the Presence of Fetal
2263 Microchimerism. *PLoS ONE* **8**(7), 1–6.

- 2264 Baardman, M. E., W. S. Kerstjens-Frederikse, R. M. F. Berger, M. K. Bakker, R. M. W. Hofstra,
2265 and T. Plösch. (2013). The Role of Maternal-Fetal Cholesterol Transport in Early Fetal
2266 Life: Current Insights. *Biology of Reproduction* **88**(1), 1–9.
- 2267 Bakker, R., S. Pierce, and D. Myers. (2017). The Role of Prostaglandins E1 and E2,
2268 Dinoprostone, and Misoprostol in Cervical Ripening and the Induction of Labor: A
2269 Mechanistic Approach. *Archives of Gynecology and Obstetrics* **296**(2), 167–79.
- 2270 Bakkour, S., C. A. R. Baker, A. F. Tarantal, L. Wen, M. P. Busch, T. H. Lee, and J. M. McCune.
2271 (2014). Analysis of Maternal Microchimerism in Rhesus Monkeys (*Macaca Mulatta*)
2272 Using Real-Time Quantitative PCR Amplification of MHC Polymorphisms. *Chimerism*
2273 **5**(1), 6–15.
- 2274 Balogh, A., E. Toth, R. Romero, K. Parej, D. Csala, N. L. Szenasi, I. Hajdu, K. Juhasz, A. F.
2275 Kovacs, and H. Meiri. (2019). Placental Galectins Are Key Players in Regulating the
2276 Maternal Adaptive Immune Response. *Frontiers in Immunology* **10**.
- 2277 Bar, A., (2009a). Calcium Transport in Strongly Calcifying Laying Birds: Mechanisms and
2278 Regulation. *Comparative Biochemistry and Physiology - A Molecular and Integrative*
2279 *Physiology* **152**(4), 447–69.
- 2280 ———. (2009b). Differential Regulation of Calbindin in the Calcium-Transporting Organs of
2281 Birds with High Calcium Requirements. *The Journal of Poultry Science* **46**(4), 267–85.
- 2282 Bar, A., J. Rosenberg, and S. Hurwitz. (1984). The Lack of Relationships between Vitamin D3
2283 Metabolites and Calcium-Binding Protein in the Eggshell Gland of Laying Birds.
2284 *Comparative Biochemistry and Physiology -- Part B* **78**(1), 75–79.

- 2285 Baratelli, F., Y. Lin, L. Zhu, Seok-Chul Yang, N. Heuzé-Vourc'h, G. Zeng, K. Reckamp, M.
2286 Dohadwala, S. Sharma, and S. M. Dubinett. (2005). Prostaglandin E₂ Induces FOXP3
2287 Gene Expression and T Regulatory Cell Function in Human CD4⁺ T Cells. *The Journal*
2288 *of Immunology* **175**(3), 1483–90.
- 2289 Bardet, C., S. Delgado, and J.Y. Sire. (2010a). MEPE evolution in mammals reveals regions and
2290 residues of prime functional importance. *Cellular and Molecular Life Sciences* **67**, 305–320.
- 2291 Bardet, C., C. Vincent, M.C. Lajarille, T. Jaffredo, and J.Y. Sire, (2010b). OC-116, the chicken
2292 ortholog of mammalian MEPE found in eggshell, is also expressed in bone cells. *Journal of*
2293 *Experimental Zoology Part B: Molecular and Developmental Evolution* **314**, 653–662.
- 2294 Barua, A., and Y. Yoshimura. (1999). Effects of Aging and Sex Steroids on the Localization of T
2295 Cell Subsets in the Ovary of Chicken, Gallus Domesticus. *General and Comparative*
2296 *Endocrinology* **114**(1), 28–35.
- 2297 Bayes-Genis, A., B. Bellosillo, O. De La Calle, M. Salido, S. Roura, F. Solé Ristol, C. Soler, et
2298 al. (2005). Identification of Male Cardiomyocytes of Extracardiac Origin in the Hearts of
2299 Women with Male Progeny: Male Fetal Cell Microchimerism of the Heart. *Journal of*
2300 *Heart and Lung Transplantation* **24**(12), 2179–83.
- 2301 Bazer, F. W. (1975). Uterine Protein Secretions: Relationship to Development of the Conceptus.
2302 *Journal of Animal Science* **41**(5), 1376–82.
- 2303 ———. (1992). Mediators of Maternal Recognition of Pregnancy in Mammals. *Proceedings of*
2304 *the Society for Experimental Biology and Medicine* **199**(4), 373–84.

- 2305 Bazer, F. W. (2013). Pregnancy Recognition Signaling Mechanisms in Ruminants and Pigs.
2306 *Journal of Animal Science and Biotechnology* **4**(1),1–10.
- 2307 Bazer, F. W, T. E. Spencer, and T. L. Ott. (1997). Interferon Tau: A Novel Pregnancy
2308 Recognition Signal. *American Journal of Reproductive Immunology* **37**(6), 412–20.
- 2309 Bazer, F. W., G. Wu, G. A. Johnson, J. Kim, and G. Song. (2011). Uterine Histotroph and
2310 Conceptus Development: Select Nutrients and Secreted Phosphoprotein 1 Affect
2311 Mechanistic Target of Rapamycin Cell Signaling in Ewes. *Biology of Reproduction*
2312 **85**(6), 1094–1107.
- 2313 Behrman, H. R., T. Endo, R. F. Aten, and B. Musicki. (1993). Corpus Luteum Function and
2314 Regression. *Reproductive Medicine Review* **2**(3), 153–80.
- 2315 Belkacemi, L., I. Bédard, L. Simoneau, and J. Lafond. (2005). Calcium Channels, Transporters
2316 and Exchangers in Placenta: A Review. *Cell Calcium* **37**(1), 1–8.
- 2317 Belkacemi, L., G. Gariépy, C. Mounier, L. Simoneau, and J. Lafond. (2004). Calbindin-D9k
2318 (CaBP9k) Localization and Levels of Expression in Trophoblast Cells from Human Term
2319 Placenta. *Cell and Tissue Research* **315**(1), 107–17.
- 2320 Belkacemi, L., L. Simoneau, and J. Lafond. (2002). Calcium-Binding Proteins. *Endocrine* **19**(1),
2321 57–64.
- 2322 Benedictusa, L., A. P. Koets, and V. P. M. G. Ruttena. (2015). The Role of Placental MHC Class
2323 I Expression in Immune Assisted Separation of the Fetal Membranes in Cattle. *Journal of*
2324 *Reproductive Immunology* **112**, 11–19.

- 2325 Bianchi, D. W., G. K. Zickwolf, G. J. Weil, S. Sylvester, and M. A. Demaria. (1996). Male Fetal
2326 Progenitor Cells Persist in Maternal Blood for as Long as 27 Years Postpartum.
2327 *Proceedings of the National Academy of Sciences* **93**(2), 705–8.
- 2328 Biazik, J. M., S. L. Parker, C. R. Murphy, and M. B. Thompson. (2012). Uterine Epithelial
2329 Morphology and Progesterone Receptors in a Mifepristone-treated Viviparous Lizard
2330 *Pseudemoia entrecasteauxii* (Squamata: Scincidae) During Gestation. *Journal of*
2331 *Experimental Zoology* **318**(2), 148–58.
- 2332 Biber, J., N. Hernando, and I. Forster. (2013). Phosphate Transporters and Their Function.
2333 *Annual Review of Physiology* **75**(1), 535–50.
- 2334 Billingham, R. E., L. Brent, and P. B. Medawar. (1953). ‘Actively Acquired Tolerance’ of
2335 Foreign Cells. *Nature* **172**(4379), 603–6.
- 2336 Bindels, R. J. (1993). Calcium Handling by the Mammalian Kidney. *The Journal of*
2337 *Experimental Biology* **184**, 89–104.
- 2338 Blackburn, D. G. (1982). Evolutionary Origins of Viviparity in the Reptilia. I. Sauria. *Amphibia-*
2339 *Reptilia* **3**(2), 185–205.
- 2340 Blackburn, D. G. (1999). Viviparity and Oviparity - Evolution and Strategies. *Encyclopedia of*
2341 *Reproduction* **4**(May), 994–1003.
- 2342 ———. (1985). Evolutionary Origins of Viviparity in the Reptilia. II. Serpentes, Amphisbaenia,
2343 and Ichthyosauria. *Amphibia Reptilia* **6**(3), 259–91.

- 2344 ———. (1992). Convergent Evolution of Viviparity, Matrotrophy, and Specializations for Fetal
2345 Nutrition in Reptiles and Other Vertebrates. *Integrative and Comparative Biology* **32**(2),
2346 313–21.
- 2347 ———. (1993). Chorioallantoic Placentation in Squamate Reptiles: Structure, Function,
2348 Development, and Evolution. *Journal of Experimental Zoology* **266**(5), 414–30.
- 2349 ———. (1995). Saltationist and Punctuated Equilibrium Models for the Evolution of Viviparity
2350 and Placentation. *Journal of Theoretical Biology* **174**(2), 199–216.
- 2351 ———. (1998). Structure, Function, and Evolution of the Oviducts of Squamate Reptiles, With
2352 Special Reference to Viviparity and Placentation. *The Journal of Experimental Zoology*
2353 **282**, 560–617.
- 2354 ———. (1999). Are Viviparity and Egg-Guarding Evolutionarily Labile in Squamates?
2355 *Herpetologica* **55**(4), 556–73.
- 2356 ———. (2000). Reptilian Viviparity: Past Research, Future Directions, and Appropriate Models.
2357 *Comparative Biochemistry and Physiology - A Molecular and Integrative Physiology*
2358 **127**(4), 391–409.
- 2359 ———. (2005). Amniote Perspectives on the Evolutionary Origins of Viviparity and
2360 Placentation. *Viviparity in Fishes* **319**, 40.
- 2361 ———. (2006). Squamate Reptiles as Model Organisms for the Evolution of Viviparity.
2362 *Herpetological Monographs* **20**(1), 131.

- 2363 ———. (2015a). Evolution of Vertebrate Viviparity and Specializations for Fetal Nutrition: A
2364 Quantitative and Qualitative Analysis. *Journal of Morphology* **276**(8), 961–90.
- 2365 ———. (2015b). Viviparous Placentotrophy in Reptiles and the Parent-Offspring Conflict.
2366 *Journal of Experimental Zoology* **324**(6), 532–48.
- 2367 ———. (2021). Functional Morphology, Diversity, and Evolution of Yolk Processing
2368 Specializations in Embryonic Reptiles and Birds. *Journal of Morphology* **282**(7), 995–
2369 1014.
- 2370 Blackburn, D. G., and A. F. Flemming. (2012). Invasive Implantation and Intimate Placental
2371 Associations in a Placentotrophic African Lizard, *Trachylepis Ivensi* (Scincidae). *Journal*
2372 *of Morphology* **273**(2), 137–59.
- 2373 Blackburn, D. G., L. Lestz, M. S. Barnes, and K. G. Powers. (2019). How Do Embryonic Turtles
2374 Process Yolk? Evidence from the Snapping Turtle, *Chelydra Serpentina* (Chelydridae).
2375 *Canadian Journal of Zoology* **97**(6), 495–501.
- 2376 Blackburn, D. G., and R. L. Lorenz. (2003). Placentation in Garter Snakes. II. Transmission EM
2377 of the Chorioallantoic Placenta of *Thamnophis Radix* and *T. Sirtalis*. *Journal of*
2378 *Morphology* **256**(2), 171–86.
- 2379 Blackburn, D. G., and L. J. Vitt. (2002). Specializations of the Chorioallantoic Placenta in the
2380 Brazilian Scincid Lizard, *Mabuya heathi*: A New Placental Morphotype for Reptiles.
2381 *Journal of Morphology* **254**(2), 121–31.

- 2382 Blackburn, D. G., and J. R. Stewart. (2021). Morphological research on amniote eggs and
2383 embryos: An introduction and historical retrospective. *Journal of Morphology* **282**(7),
2384 1024–1046
- 2385 Blaine, J., M. Chonchol, and M. Levi. (2015). Renal Control of Calcium, Phosphate, and
2386 Magnesium Homeostasis. *Clinical Journal of the American Society of Nephrology* **10**(7),
2387 1257–72.
- 2388 Blomberg, L. A., L. L. Schreier, H. David Guthrie, G. L. Sample, J. Vallet, T. Caperna, and T.
2389 Ramsay. (2010). The Effect of Intrauterine Growth Retardation on the Expression of
2390 Developmental Factors in Porcine Placenta Subsequent to the Initiation of Placentation.
2391 *Placenta* **31**(6), 549–52.
- 2392 Boehm, T., M. Hirano, S. J. Holland, S. Das, M. Schorpp, and M. D. Cooper. (2018). Evolution
2393 of Alternative Adaptive Immune Systems in Vertebrates. *Annual Review of Immunology*
2394 **36**, 19–42.
- 2395 Bonnet, X., G. Naulleau, D. Bradshaw, and R. Shine. (2001). Changes in Plasma Progesterone in
2396 Relation to Vitellogenesis and Gestation in the Viviparous Snake *Vipera aspis*. *General*
2397 *and Comparative Endocrinology* **121**(1), 84–94.
- 2398 Bonnet, X., G. Naulleau, and R. Shine. (2017). The Evolutionary Economics of Embryonic-Sac
2399 Fluids in Squamate Reptiles. *American Naturalist* **189**(3), 333–44.
- 2400 Borgnia, M., S. Nielsen, A. Engel, and P. Agre. (1999). Cellular and Molecular Biology of the
2401 Aquaporin Water Channels. *Annual Reviews in Biochemistry*. **68**, 425–58.

- 2402 Borziak, K., A. Álvarez-Fernández, T. L. Karr, T. Pizzari, and S. Dorus. (2016). The Seminal
2403 Fluid Proteome of the Polyandrous Red Junglefowl Offers Insights into the Molecular
2404 Basis of Fertility, Reproductive Ageing and Domestication. *Scientific Reports* **6**, 1–15.
- 2405 Boyson, J. E., K. K. Iwanaga, T. G. Golos, and D. I. Watkins. (1997). Identification of a Novel
2406 MHC Class I Gene, Mamu-AG, Expressed in the Placenta of a Primate with an
2407 Inactivated G Locus. *Journal of Immunology (Baltimore, Md: 1950)* **159**(7), 3311–21.
- 2408 Brace, R. A. (1997). Physiology of Amniotic Fluid Volume Regulation. *Clinical Obstetrics and*
2409 *Gynecology* **40**(2), 280–89.
- 2410 Brandley, M. C., R. L. Young, D. L. Warren, M. B. Thompson, and G. P. Wagner. (2012).
2411 Uterine Gene Expression in the Live-Bearing Lizard, *Chalcides Ocellatus*, Reveals
2412 Convergence of Squamate Reptile and Mammalian Pregnancy Mechanisms. *Genome*
2413 *Biology and Evolution* **4**(3), 394–411.
- 2414 Brawand, D., W. Wahli, and H. Kaessmann. (2008). Loss of Egg Yolk Genes in Mammals and
2415 the Origin of Lactation and Placentation. *PLoS Biology* **6**(3), 0507–17.
- 2416 Braz, H. B., R.R. Scartozzoni, and S.M. Almeida-Santos, S. M. (2016). Reproductive modes of
2417 the South American water snakes: A study system for the evolution of viviparity in
2418 squamate reptiles. *Zoologischer Anzeiger* **263**, 33-44.
- 2419 Braz, H. B., S. M. Almeida-Santos, C. R. Murphy, and M. B. Thompson. (2018). Uterine and
2420 Eggshell Modifications Associated with the Evolution of Viviparity in South American
2421 Water Snakes (*Helicops* spp.). *Journal of Experimental Zoology* **330**(3), 165–80.

2422 Brennan, S. C., U. Thiem, S. Roth, A. Aggarwal, I. S. Fetahu, S. Tennakoon, A. R. Gomes, et al.
2423 (2013). Calcium Sensing Receptor Signaling in Physiology and Cancer. *Biochimica et*
2424 *Biophysica Acta - Molecular Cell Research* **1833**(7), 1732–44.

2425 Breuss, J. M., N. Gillett, L. Lu, D. Sheppard, and R. Pytela. (1993). Restricted Distribution of
2426 Integrin B6 mRNA in Primate Epithelial Tissues. *Journal of Histochemistry and*
2427 *Cytochemistry* **41**(10), 1521–27.

2428 Brionne, A., Y. Nys, C. Hennequet-Antier, and J. Gautron. (2014). Hen Uterine Gene Expression
2429 Profiling during Eggshell Formation Reveals Putative Proteins Involved in the Supply of
2430 Minerals or in the Shell Mineralization Process. *BMC Genomics* **15**(202), 1–18.

2431 Bronner, F. (2003). Mechanisms of Intestinal Calcium Absorption. In *Journal of Cellular*
2432 *Biochemistry*. **88**, 387–93.

2433 Bulmer, J. N., L. Morrison, M. Longfellow, A. Ritson, and De. Pace. (1991). Granulated
2434 Lymphocytes in Human Endometrium: Histochemical and Immunohistochemical
2435 Studies. *Human Reproduction* **6**(6), 791–98.

2436 Bulmer, J. N., P. J. Williams, and G. E. Lash. (2010). Immune Cells in the Placental Bed.
2437 *International Journal of Developmental Biology* **54**(2–3), 281–94.

2438 Burbrink, F. T., F. G. Grazziotin, A. Pyron, D. Cundall, S. Donnellan, F. Irish, J. S. Keogh, F.
2439 Kraus, R. W. Murphy, B. Noonan, C. J. Raxworthy, S. Ruane, A. R. Lemmon, E.
2440 Moriarty Lemmon, H. Zaher. (2020). Interrogating Genomic-Scale Data for Squamata
2441 (Lizards, Snakes, and Amphisbaenians) Shows No Support for Key Traditional
2442 Morphological Relationships. *Systematic Biology* **69**(3), 502–20.

- 2443 Burlingham, W., and W. Bracamonte-Baran (2015). Non-Inherited Maternal Antigens,
2444 Pregnancy, and Allotolerance. *Biomedical Journal* **38**(1), 39–51.
- 2445 Burlingham, W. (2010). Chimerism, Tolerance, and Twins. *Obstetrics & Gynecology* **116**(2),
2446 475–76.
- 2447 Burton, F. G., and S. G. Tullett. (1985). Respiration of Avian Embryos. *Comparative*
2448 *Biochemistry and Physiology -- Part A: Physiology* **82**(4), 735–44.
- 2449 Burton, G. J., A. L. Watson, J. Hempstock, J. N. Skepper, and E. Jauniaux. (2002). Uterine
2450 Glands Provide Histiotrophic Nutrition for the Human Fetus during the First Trimester of
2451 Pregnancy. *Journal of Clinical Endocrinology and Metabolism* **87**(6), 2954–59.
- 2452 Cadet, P., P. L. Rady, S. K. Tyring, R. B. Yandell, and T. K. Hughes. (1995). Interleukin-10
2453 Messenger Ribonucleic Acid in Human Placenta: Implications of a Role for Interleukin-
2454 10 in Fetal Allograft Protection. *American Journal of Obstetrics and Gynecology* **173**(1),
2455 25–29.
- 2456 Callard, I. P., L. A. Fileti, L. E. Perez, L. A. Sorbera, L. L. Klosterman, P. Tsang, J. A.
2457 Mccracken, et al. (1992). Role of the Corpus Luteum and Progesterone in the Evolution
2458 of Vertebrate Viviparity. *Integrative and Comparative Biology* **32**(2), 264–75.
- 2459 Camaiti, M., Evans, A.R., Hipsley, C.A. and Chapple, D.G. (2021), A farewell to arms and legs:
2460 a review of limb reduction in squamates. *Biological Reviews* **96**, 1035-1050.
- 2461 Canalis E., Economides A.N., Gazzo E. (2003). Bone Morphogenetic Proteins, their
2462 Antagonists, and the Skeleton *Endocr Rev.* **24**(2), 218–35.

- 2463 Caniggia, I., H. Mostachfi, J. Winter, M. Gassmann, S. J. Lye, M. Kuliszewski, and M. Post.
2464 (2000). Hypoxia-Inducible Factor-1 Mediates the Biological Effects of Oxygen on
2465 Human Trophoblast Differentiation through TGF β 3. *Journal of Clinical Investigation*
2466 **105**(5), 577–87.
- 2467 Capecchi, E., Lobo, J.L., I., Laña, J. I. Espinosa-Ramos, and N. Kasabov. (2020). Modelling gene
2468 interaction networks from time-series gene expression data using evolving spiking neural
2469 networks. *Evolving Systems* **11**, 599–613.
- 2470 Carosella, E. D., N. Rouas-Freiss, D. Tronik-Le Roux, P. Moreau, and J. LeMaoult. (2015).
2471 HLA-G: An Immune Checkpoint Molecule. *Advances in Immunology* **127**, 33–144.
- 2472 Carter, A. M. (2009). Evolution of Factors Affecting Placental Oxygen Transfer. *Placenta* **30**,
2473 19–25.
- 2474 Carter, A. M. (2012). Evolution of Placental Function in Mammals: The Molecular Basis of Gas
2475 and Nutrient Transfer, Hormone Secretion, and Immune Responses. *Physiological*
2476 *Reviews* **92**(4), 1543–76.
- 2477 Casey, M. L., and P. C. MacDonald. (1997). The Endocrinology of Human Parturition. *Annals of*
2478 *the New York Academy of Sciences* **828**, 273–84.
- 2479 Castracane, V. D., and J. W. Goldzieher. (1986). Timing of the Luteal-Placental Shift in the
2480 Baboon (*Papio Cynocephalus*). *Endocrinology* **118**(2), 506–12.
- 2481 Caterson B, J. Melrose (2018). Keratan sulfate, a complex glycosaminoglycan with unique
2482 functional capability. *Glycobiology* **28**(4), 182-206.

- 2483 Challis, J. R. G., F. H. Bloomfield, A. D. Bocking, V. Casciani, H. Chisaka, K. Connor, X.
2484 Dong, P. Gluckman, J. E. Harding, and J. Johnstone. (2005). Fetal Signals and
2485 Parturition. *Journal of Obstetrics and Gynaecology Research* **31**(6), 492–99.
- 2486 Challis, J. R., C. J. Lockwood, L. Myatt, J. E. Norman, J. F. Strauss, and F. Petraglia. (2009).
2487 Inflammation and Pregnancy. *Reproductive Sciences* **16**(2), 206–15.
- 2488 Challis, J. R. G., S. G. Matthews, W. Gibb, and S. J. Lye. (2000). Endocrine and Paracrine
2489 Regulation of Birth at Term and Preterm. *Endocrine Reviews* **21**(5), 514–50.
- 2490 Chamberlain, P. F., F. A. Manning, I. Morrison, C. R. Harman, and I. R. Lange. (1984).
2491 Ultrasound Evaluation of Amniotic Fluid Volume: I. The Relationship of Marginal and
2492 Decreased Amniotic Fluid Volumes to Perinatal Outcome. *American Journal of*
2493 *Obstetrics and Gynecology* **150**(3), 245–49.
- 2494 Chaouat, G. (2016). Reconsidering the Medawar Paradigm Placental Viviparity Existed for
2495 Eons, Even in Vertebrates; without a ‘Problem’: Why Are Tregs Important for
2496 Preeclampsia in Great Apes ? *Journal of Reproductive Immunology* **114**, 48–57.
- 2497 Chaouat, G., J. Tranchot Diallo, J. L. Volumenie, E. Menu, G. Gras, G. Delage, and B. Mognetti.
2498 (1997). Immune Suppression and Th1/Th2 Balance in Pregnancy Revisited: A (Very)
2499 Personal Tribute to Tom Wegmann. *American Journal of Reproductive Immunology*
2500 **37**(6), 427–34.
- 2501 Chaouat, G., M. Petitbarat, S. Dubanchet, M. Rahmati, and N. Ledée. (2010). Tolerance to the
2502 Foetal Allograft? *American Journal of Reproductive Immunology* **63**(6), 624–36.

- 2503 Charpigny, G., M. J. Leroy, M. Breuiller-Fouché, Z. Tanfin, S. Mhaouty-Kodja, P. Robin, D.
2504 Leiber, et al. (2003). A Functional Genomic Study to Identify Differential Gene
2505 Expression in the Preterm and Term Human Myometrium. *Biology of Reproduction*
2506 **68**(6), 2289–96.
- 2507 Chatterjee-Hasrouni, S., and P. K. Lala. (1982). On Murine of Paternal Trophoblast H-2K
2508 Antigen Cells in Vivo. *Journal of Experimental Medicine* **155**(6), 1679–89.
- 2509 Chattopadhyay, A., N. Robinson, J. K. Sandhu, B. B. Finlay, S. Sad, and L. Krishnan. (2010).
2510 Salmonella Enterica Serovar Typhimurium-Induced Placental Inflammation and Not
2511 Bacterial Burden Correlates with Pathology and Fatal Maternal Disease. *Infection and*
2512 *Immunity* **78**(5), 2292–2301.
- 2513 Chaturvedi, V., J. M. Ertelt, T. T. Jiang, J. M. Kinder, L. Xin, K. J. Owens, H. N. Jones, and S.
2514 S. Way. (2015). CXCR3 Blockade Protects against *Listeria Monocytogenes* Infection-
2515 Induced Fetal Wastage. *Journal of Clinical Investigation* **125**(4), 1713–25.
- 2516 Chavan, A. R., O. W. Griffith, and G. P. Wagner. (2017). The Inflammation Paradox in the
2517 Evolution of Mammalian Pregnancy: Turning a Foe into a Friend. *Current Opinion in*
2518 *Genetics and Development* **47**, 24–32.
- 2519 Chen, L., C. Chu, X. Kong, G. Huang, T. Huang, and Y. Dong Cai. (2015). A Hybrid
2520 Computational Method for the Discovery of Novel Reproduction-Related Genes. *PLoS*
2521 *ONE* **10**(3), 1–15.
- 2522 Chien, Y. C., M. T. Hincke, and M. D. McKee. (2008). Avian Eggshell Structure and
2523 Osteopontin. *Cells Tissues Organs* **189**(1–4), 38–43.

- 2524 ———. (2009). Ultrastructure of Avian Eggshell during Resorption Following Egg Fertilization.
2525 *Journal of Structural Biology* **168**(3): 527–38.
- 2526 Chmurzyńska, A., (2006). The Multigene Family of Fatty Acid-Binding Proteins (FABPs):
2527 Function, Structure and Polymorphism. *Journal of Applied Genetics* **47**(1), 39–48.
- 2528 Choi, S., S. Han, N. H. Kim, Y. N. Lee. (2018). A Comparative Study of Eggshells of Gekkota
2529 with Morphological, Chemical Compositional and Crystallographic Approaches and its
2530 Evolutionary Implications. *PLOS ONE*. **13**(6), e0199496
- 2531 Seung Choi, N.-H. Kim, H.-I Kim, J.J. Kweon, S.K. Lee, S. Zhang, D.J. Varricchio. (2022)
2532 Preservation of aragonite in Late Cretaceous (Campanian) turtle eggshell
2533 *Palaeogeography, Palaeoclimatology, Palaeoecology* **585**, 110741.
- 2534 Chowdhury, S. D., and R. H. Davis. (1995). Influence of Dietary Osteolathyrogens on the
2535 Ultrastructure of Shell and Membranes of Eggs from Laying Hens. *British Poultry*
2536 *Science* **36**(4), 575–83.
- 2537 Christiaens, I., D. B. Zaragoza, L. Guilbert, S. A. Robertson, B. F. Mitchell, and D. M. Olson.
2538 (2008). Inflammatory Processes in Preterm and Term Parturition. *Journal of*
2539 *Reproductive Immunology* **79**(1), 50–57.
- 2540 Chu, T. M., and E. Kawinski. (1998). Plasmin, Subtilisin-like Endoproteases, Tissue
2541 Plasminogen Activator, and Urokinase Plasminogen Activator Are Involved in Activation
2542 of Latent TGF- β 1 in Human Seminal Plasma. *Biochemical and Biophysical Research*
2543 *Communications* **253**(1), 128–34.

- 2544 Chuliver, M., Scanferla A., Smith K. T. (2022). Live birth in a 47-million-year-old snake. *The*
2545 *Science of Nature* **109**(6), 56.
- 2546 Cindrova-Davies, T., E. Jauniaux, M. G. Elliot, S. Gong, G. J. Burton, and D. S. Charnock-
2547 Jones. (2017). RNA-Seq Reveals Conservation of Function among the Yolk Sacs of
2548 Human, Mouse, and Chicken. *Proceedings of the National Academy of Sciences* 114(24),
2549 E4753–61.
- 2550 Coleman, J. R., and A. R. Terepka. (1972). Electron Probe Analysis of the Calcium Distribution
2551 in Cells of the Embryonic Chick Chorioallantoic Membrane. I. A Critical Evaluation of
2552 Techniques. *The Journal of Histochemistry and Cytochemistry* **20**(6), 401–13.
- 2553 Cooke, P. S., T. E. Spencer, F. F. Bartol, and K. Hayashi. (2013). Uterine Glands: Development,
2554 Function and Experimental Model Systems. *Molecular Human Reproduction* **19**(9),
2555 547–58.
- 2556 **Cornelis, G., Funk, M., Vernochet, C., Leal, F., Tarazona, O. A.,** Meurice, G., ... &
2557 Heidmann, T. (2017). An endogenous retroviral envelope syncytin and its cognate
2558 receptor identified in the viviparous placental Mabuya lizard. *Proceedings of the National*
2559 *Academy of Sciences* **114**(51), E10991-E11000.
- 2560 Cornetti, L., O. W. Griffith, A. Benazzo, A. Panziera, C. M. Whittington, M. B. Thompson, C.
2561 Vernesi, and G. Bertorelle. (2018). Candidate Genes Involved in the Evolution of
2562 Viviparity: A RAD Sequencing Experiment in the Lizard *Zootoca vivipara* (Squamata:
2563 Lacertidae). *Zoological Journal of the Linnean Society* **183**(1), 196–207.

- 2564 Corso, G., G. M. Delitala, and M. Carcupino. (2000). Uterine Morphology during the Annual
2565 Cycle in *Chalcides ocellatus tiligugu* (Squamata: Scincidae). *Journal of Morphology*
2566 **243**(2), 153–65.
- 2567 Corso, G., M. Pala, A. M. Pinna, and M. Carcupino. (1988). Aspetti Morfofunzionali
2568 Dell’ovidutto Di *Chalcides Ocellatus Tiligugu* (Squamata, Scincidae). *Italian*
2569 *Journal of Anatomy and Embryology* **93**(4), 237–51.
- 2570 Cox, C. L., R. T. Peaden, and R. M. Cox. (2015). The Metabolic Cost of Mounting an Immune
2571 Response in Male Brown Anoles (*Anolis sagrei*). *Journal of Experimental Zoology*
2572 **323**(10), 689–95.
- 2573 Cree, A., and L. J. Guillette. (1991). Effect Of-Adrenergic Stimulation on Uterine Contraction in
2574 Response to Arginine Vasotocin and Prostaglandin F2a in the Gecko *Hoplodactylus*
2575 *maculatus*. *Biology of Reproduction*. **44**
- 2576 Cuellar, H. S. (1979). Disruption of Gestation and Egg Shelling in Deluteinized Oviparous
2577 Whiptail Lizards *Cnemidophorus uniparens* (Reptilia: Teiidae). *General and*
2578 *Comparative Endocrinology* **39**(2), 150–57.
- 2579 Custodia-Lora, N., A. Novillo, and I. P. Callard. (2004). Regulation of Hepatic Progesterone and
2580 Estrogen Receptors in the Female Turtle, *Chrysemys Picta*: Relationship to
2581 Vitellogenesis. *General and Comparative Endocrinology* **136**(2), 232–40.
- 2582 Damiano, A. E. 2011. Review: Water Channel Proteins in the Human Placenta and Fetal
2583 Membranes. *Placenta* **32**, S207–11.

- 2584 Das, S. C., N. Isobe, and Y. Yoshimura. (2008). Mechanism of Prolonged Sperm Storage and
2585 Sperm Survivability in Hen Oviduct: A Review. *American Journal of Reproductive*
2586 *Immunology* **60**(6), 477–81.
- 2587 Davies, C. J., J. R. Hill, J. L. Edwards, F. N. Schrick, P. J. Fisher, J. A. Eldridge, and D. H.
2588 Schlafer. (2004). Major Histocompatibility Antigen Expression on the Bovine Placenta:
2589 Its Relationship to Abnormal Pregnancies and Retained Placenta. *Animal Reproduction*
2590 *Science* **82–83**, 267–80.
- 2591 Davies, C. J., J. A. Eldridge, P. J. Fisher, and D. H. Schlafer. (2006). Evidence for Expression of
2592 Both Classical and Non-classical Major Histocompatibility Complex Class I Genes in
2593 Bovine Trophoblast Cells. *American Journal of Reproductive Immunology* **55**(3), 188–
2594 200.
- 2595 de Fraipont, M., J. Clobert, and R. Barbault. (1996). The Evolution of Oviparity with Egg
2596 Guarding and Viviparity in Lizards and Snakes: A Phylogenetic Analysis. *Evolution*
2597 **50**(1), 391–400.
- 2598 De Rensis, F., R. Saleri, P. Tummaruk, M. Techakumphu, and R. N. Kirkwood. (2012).
2599 Prostaglandin F_{2α} and Control of Reproduction in Female Swine: A Review.
2600 *Theriogenology* **77**(1), 1–11.
- 2601 Denison, F. C., A. A. Calder, and R. W. Kelly. (1999). The Action of Prostaglandin E₂ on the
2602 Human Cervix: Stimulation of Interleukin 8 and Inhibition of Secretory Leukocyte
2603 Protease Inhibitor. *American Journal of Obstetrics and Gynecology* **180**(3I), 614–20.

- 2604 Denison, F. C., V. E. Grant, A. A. Calder, and R. W. Kelly. (1999). Seminal Plasma
2605 Components Stimulate Interleukin-8 and Interleukin-10 Release. *Molecular Human*
2606 *Reproduction* **5**(3), 220–26.
- 2607 Denison, F. C., R. W. Kelly, A. A. Calder, and S. C. Riley. (1998). Cytokine Secretion by
2608 Human Fetal Membranes, Decidua and Placenta at Term. *Human Reproduction* **13**(12),
2609 3560–65.
- 2610 Diaz, J. A., A. L. Alonso-Gomez, and M. J. Delgado. (1994). Seasonal Variation of Gonadal
2611 Development, Sexual Steroids, and Lipid Reserves in a Population of the Lizard
2612 *Psammodromus algirus*. *Society for the Study of Amphibia* **28**(2), 199–205.
- 2613 Doty, A., W. C. Buhi, S. Benson, K. E. Scoggin, M. Pozor, M. Macpherson, M. Mutz, and M. H.
2614 T. Troedsson. (2011). Equine CRISP3 Modulates Interaction between Spermatozoa and
2615 Polymorphonuclear Neutrophils. *Biology of Reproduction* **85**(1), 157–64.
- 2616 Druckmann, R., and M. A. Druckmann. (2005). Progesterone and the Immunology of Pregnancy.
2617 *Journal of Steroid Biochemistry and Molecular Biology* **97**(5), 389–96.
- 2618 Duan, C., and J. B. Allard. (2020). Insulin-Like Growth Factor Binding Protein-5 in Physiology
2619 and Disease. *Frontiers in Endocrinology*. **11**.
- 2620 Duncan, W. C. (2000). The Human Corpus Luteum: Remodelling during Luteolysis and
2621 Maternal Recognition of Pregnancy. *Reviews of Reproduction* **5**(1), 12–17.
- 2622 Duncan, W. C., A. S. McNeilly, and P. J. Illingworth. (1998). The Effect of Luteal ‘rescue’
2623 on the Expression and Localization of Matrix Metalloproteinases and Their Tissue

- 2624 Inhibitors in the Human Corpus Luteum. *Journal of Clinical Endocrinology and*
2625 *Metabolism* **83**(7), 2470–78.
- 2626 Durso, A. M., and S. S. French. (2018). Stable Isotope Tracers Reveal a Trade-off between
2627 Reproduction and Immunity in a Reptile with Competing Needs. *Functional Ecology*
2628 **32**(3), 648–56.
- 2629 Ecay, T. W., J. R. Stewart, and D. G. Blackburn. (2004). Expression of Calbindin-D28K by Yolk
2630 Sac and Chorioallantoic Membranes of the Corn Snake, *Elaphe guttata*. *Journal of*
2631 *Experimental Zoology* **302**(6), 517–25.
- 2632 Ecay, T. W., J. R. Stewart, G. Wiessner, and B. Heulin. (2017). Ex Utero Culture of Viviparous
2633 Embryos of the Lizard, *Zootoca vivipara*, Provides Insights into Calcium Homeostasis
2634 during Development. *Comparative Biochemistry and Physiology -Part A: Molecular and*
2635 *Integrative Physiology* **206**, 63–68.
- 2636 Elinson, R. P., and J. R. Stewart. (2014). The Corn Snake Yolk Sac Becomes a Solid Tissue
2637 Filled with Blood Vessels and Yolk-Rich Endodermal Cells. *Biology Letters* **10**(1).
- 2638 Elinson, R. P., J. R. Stewart, L. J. Bonneau, and D. G. Blackburn. (2014). Amniote Yolk Sacs:
2639 Diversity in Reptiles and a Hypothesis on Their Origin. *International Journal of*
2640 *Developmental Biology* **58**(10–12), 889–94.
- 2641 Elliott, C. L. (2001). Nuclear Factor-Kappa B Is Essential for up-Regulation of Interleukin-8
2642 Expression in Human Amnion and Cervical Epithelial Cells. *Molecular Human*
2643 *Reproduction* **7**(8), 787–90.

- 2644 Ellis, M. J., J. H. Livesey, W. J. Inder, T. C. R. Prickett, and R. Reid. (2002). Plasma
2645 Corticotropin-Releasing Hormone and Unconjugated Estriol in Human Pregnancy:
2646 Gestational Patterns and Ability to Predict Preterm Delivery. *American Journal of*
2647 *Obstetrics and Gynecology* **186**(1), 94–99.
- 2648 Emanuel, R. L., B. G. Robinson, E. W. Seely, S. W. Graves, I. Kohane, D. Saltzman, R. Barbieri,
2649 and J. A. Majzoub. (1994). Corticotrophin Releasing Hormone Levels in Human Plasma
2650 and Amniotic Fluid during Gestation. *Clinical Endocrinology* **40**(2), 257–62.
- 2651 Enders, A. C., W. A. Wimsatt, and B. F. King. (1976). Cytological Development of Yolk Sac
2652 Endoderm and Protein-absorptive Mesothelium in the Little Brown Bat, *Myotis*
2653 *lucifugus*. *American Journal of Anatomy* **146**(1), 1–29.
- 2654 Erben, R. G., and O. Andrukhova. (2015). FGF23 Regulation of Renal Tubular Solute Transport.
2655 *Current Opinion in Nephrology and Hypertension* **24**(5), 450–56.
- 2656 Erlebacher, A. (2001). Why Isn't the Fetus Rejected? *Current Opinion in Immunology* **13**(5),
2657 590–93.
- 2658 ———. (2013). Immunology of the Maternal-Fetal Interface. *Annual Review of Immunology* **31**,
2659 387–411.
- 2660 Evans, C. H., T. S. Lee, and A. A. Flugelman. (1995). Spermine-Directed Immunosuppression of
2661 Cervical Carcinoma Cell Sensitivity to a Majority of Lymphokine-Activated Killer
2662 Lymphocyte Cytotoxicity. *Natural Immunity* **14**(3), 157.

- 2663 Evans, P. C., N. Lambert, S. Maloney, D. E. Furst, J. M. Moore, and J. L. Nelson. (1999). Long-
2664 Term Fetal Microchimerism in Peripheral Blood Mononuclear Cell Subsets in Healthy
2665 Women and Women with Scleroderma. *Blood* **93**(6), 2033–37.
- 2666 Ewy, Z. (1970). Effect of Vasotocin and Oxytocin on Oviposition in the Hen. Department of
2667 Physiology, College of Agriculture, **12**, 549-550.
- 2668 Faas, M. M., and P. de Vos. (2017). Uterine NK Cells and Macrophages in Pregnancy. *Placenta*
2669 **56**, 44–52.
- 2670 Faulk, W. P., and J. A. McIntyre. (1983). Immunological Studies of Human Trophoblast:
2671 Markers, Subsets and Functions. *Immunological Reviews* **75**(1), 139–75.
- 2672 Faulk, W. P., and A. Temple. (1976). Distribution of B2 Microglobulin and HLA in Chorionic
2673 Villi of Human Placentae. *Nature* **262** (5571), 799–802.
- 2674 Fazleabas, A. T., J. J. Kim, and Z. Strakova. (2004). Implantation: Embryonic Signals and the
2675 Modulation of the Uterine Environment - A Review. *Placenta* **25**, 26–31.
- 2676 Fazleabas, A. T. (2007). Physiology and Pathology of Implantation in the Human and Nonhuman
2677 Primate. In *Seminars in Reproductive Medicine* **25**, 405–9.
- 2678 Fedakâr, A., S. Semiz, and N. Peker. (2016). Clinical Features of Babies Born to Mothers with
2679 Oligohydramnios: A Two Years' Experience. *Journal of Pregnancy and Child Health*
2680 **3**(2).

- 2681 Fenwick, A. M., H. W. Greene, and C. L. Parkinson. (2011). The Serpent and the Egg:
2682 Unidirectional Evolution of Reproductive Mode in Vipers? *Journal of Zoological*
2683 *Systematics and Evolutionary Research* **50**(1), 59–66.
- 2684 Fergusson, B., and S. D. Bradshaw. (1991). Plasma Arginine Vasotocin, Progesterone, and
2685 Luteal Development during Pregnancy in the Viviparous Lizard *Tiliqua rugosa*. *General*
2686 *and Comparative Endocrinology* **82**(1), 140–51.
- 2687 Fernandez, M. S., M. Araya, and J. L. Arias. (1997). Eggshells Are Shaped by a Precise Spatio-
2688 Temporal Arrangement of Sequentially Deposited Macromolecules. *Matrix Biology*
2689 **16**(1), 13–20.
- 2690 Fernandez, M., A. Moya, L. Lopez, and J. L. Arias. (2001). Secretion Pattern, Ultrastructural
2691 Localization and Function of Extracellular Matrix Molecules Involved in Eggshell
2692 Formation. *Matrix Biology* **19**(8), 793–803.
- 2693 Ferner, K., and A. Mess. (2011). Respiratory Physiology & Neurobiology Evolution and
2694 Development of Fetal Membranes and Placentation in Amniote Vertebrates.
2695 *Respiratory Physiology & Neurobiology* **178**(1), 39–50.
- 2696 Fitch, H S. (1970). Reproductive Cycles in Lizards and Snakes. *University of Kansas Museum of*
2697 *Natural History Miscellaneous Publications* **52**, 1–247.
- 2698 Flemming, A. F., and D. G. Blackburn. (2003). Evolution of Placental Specializations in
2699 Viviparous African and South American Lizards. *Journal of Experimental Zoology Part*
2700 *A: Comparative Experimental Biology* **299**(1), 33–47.

- 2701 Florio, P., L. Cobellis, J. Woodman, F. M. Severi, E. A. Linton, and F. Petraglia. (2002). Levels
2702 of Maternal Plasma Corticotropin-Releasing Factor and Urocortin during Labor. *The*
2703 *Journal of the Society for Gynecologic Investigation* **9**(4), 233–37.
- 2704 Ford, S. P. (1997). Embryonic and Fetal Development in Different Genotypes in Pigs. *Journal of*
2705 *Reproduction and Fertility*. **52**,165–76.
- 2706 Forde, N., M. E. Beltman, G. B. Duffy, P. Duffy, J. P. Mehta, P. Ó’Gaora, J. F. Roche, P.
2707 Lonergan, and M. A. Crowe. (2011). Changes in the Endometrial Transcriptome during
2708 the Bovine Estrous Cycle: Effect of Low Circulating Progesterone and Consequences for
2709 Conceptus Elongation. *Biology of Reproduction* **84**(2), 266–78.
- 2710 Foster, C. S. P., M. B. Thompson, J. U. van Dyke, M. C. Brandley, and C. M. Whittington.
2711 (2020). Emergence of an Evolutionary Innovation: Gene Expression Differences
2712 Associated with the Transition between Oviparity and Viviparity. *Molecular Ecology*
2713 **29**(7), 1315–27.
- 2714 **Foster, C.S.P., J.U. Van Dyke, M.B. Thompson, N.M.A. Smith, C.A. Simpfendorfer, C.R.**
2715 **Murphy, and C.M. Whittington.** (2022) Different Genes are Recruited During
2716 Convergent Evolution of Pregnancy and the Placenta. *Molecular Biology and Evolution*
2717 **39**(4), msac077
- 2718 Fox, S. L, and L. J. Guillette Jr. (1987). Luteal Morphology, Atresia, and Plasma Progesterone
2719 Concentrations during the Reproductive Cycle of Two Oviparous Lizards, *Crotaphytus*
2720 *collaris* and *Eumeces obsoletus*. *American Journal of Anatomy* **179**(4), 324–32.

- 2721 Francesch, A., J. Estany, L. Alfonso, and M. Iglesias. (1997). Genetic Parameters for Egg
2722 Number, Egg Weight, and Eggshell Color in Three Catalan Poultry Breeds. *Poultry*
2723 *Science* **76**(12), 1627–31.
- 2724 Frankenberg, S., and M. B. Renfree. (2018). Conceptus Coats of Marsupials and Monotremes. In
2725 *Current Topics in Developmental Biology* **130**, 357–77.
- 2726 Fregoso, S. P., J. R. Stewart, and T. W. Eday. (2010). Embryonic Mobilization of Calcium in a
2727 Viviparous Reptile: Evidence for a Novel Pattern of Placental Calcium Secretion.
2728 *Comparative Biochemistry and Physiology - A Molecular and Integrative Physiology*
2729 **156**(1), 147–50.
- 2730 French, S. S., G. I. H. Johnston, and M. C. Moore. (2007). Immune Activity Suppresses
2731 Reproduction in Food-Limited Female Tree Lizards *Urosaurus ornatus*. *Functional*
2732 *Ecology* **21**(6), 1115–22.
- 2733 Freyer, C., and M. B. Renfree. (2009). The Mammalian Yolk Sac Placenta. *Journal of*
2734 *Experimental Zoology Part B: Molecular and Developmental Evolution* **312**(6), 545–54.
- 2735 Freyer, C., U. Zeller, and M. B. Renfree. (2003). The Marsupial Placenta: A Phylogenetic
2736 Analysis. *Journal of Experimental Zoology* **299**(1), 59–77.
- 2737 Fujiki, Y., K. L. Johnson, H. Tighiouart, I. Peter, and D. W. Bianchi. (2008). Fetomaternal
2738 Trafficking in the Mouse Increases as Delivery Approaches and Is Highest in the
2739 Maternal Lung. *Biology of Reproduction* **79**(5), 841–48.

- 2740 Funderburgh, J. L. (2002). Keratan sulfate biosynthesis. *International Union of Biochemistry*
2741 *and Molecular Biology Life* **54**(4), 187-94.
- 2742 Gao, H., G. Wu, T. E. Spencer, G. A. Johnson, and F. W. Bazer. (2009). Select Nutrients in the
2743 Ovine Uterine Lumen. IV. Expression of Neutral and Acidic Amino Acid Transporters in
2744 Ovine Uteri and Peri-Implantation Conceptuses1. *Biology of Reproduction* **80**(6), 1196–
2745 1208.
- 2746 Gao, J. F., Y. F. Qu, L. G. Luo, and X. Ji. (2010). Evolution of Reptilian Viviparity: A Test of the
2747 Maternal Manipulation Hypothesis in a Temperate Snake, *Gloydius brevicaudus*
2748 (*Viperidae*). *Zoological Science* **27**(3), 248–55.
- 2749 Gao, W., Y. B. Sun, W. W. Zhou, Z. J. Xiong, L. Chen, H. Li, T. T. Fu, et al. (2019). Genomic
2750 and Transcriptomic Investigations of the Evolutionary Transition from Oviparity to
2751 Viviparity. *Proceedings of the National Academy of Sciences* **116**(9), 3646-3655.
- 2752 García-Collazo, R., M. Villagrán-Santa Cruz, E. Morales-Guillaumin, R. N. M. Lázaro, and F. R.
2753 Méndez-De La Cruz. (2012). Egg Retention and Intrauterine Embryonic Development in
2754 *Sceloporus aeneus* (Reptilia: Phrynosomatidae): Implications for the Evolution of
2755 Viviparity. *Revista Mexicana de Biodiversidad* **83**(3), 802–8.
- 2756 Gautron, J., M. T. Hincke, and Y. Nys. 1997. Precursor Matrix Proteins in the Uterine Fluid
2757 Change with Stages of Eggshell Formation in Hens. *Connective Tissue Research* **36**(3),
2758 195–210.

- 2759 Gautron, J., M. T. Hincke, M. Panhéleux, J. M. Garcia-Ruiz, T. Boldicke, and Y. Nys. (2001).
2760 Ovotransferrin Is a Matrix Protein of the Hen Eggshell Membranes and Basal Calcified
2761 Layer. *Connect Tissue Res* **42**(4), 255–67.
- 2762 Gautron, J., L. Stapane, N. le Roy, Y. Nys, A. B. Rodriguez-Navarro, and M. T. Hincke. (2021).
2763 Avian Eggshell Biomineralization: An Update on Its Structure, Mineralogy and Protein
2764 Tool Kit. *BMC Molecular and Cell Biology* **22**(11).
- 2765 Gautron, J., M. T. Hincke, K. Mann, M. Panhéleux, M. Bain, M. D. McKee, S. E. Solomon, and
2766 Y. Nys. (2001). Ovocalyxin-32, a Novel Chicken Eggshell Matrix Protein. Isolation,
2767 Amino Acid Sequencing, Cloning, and Immunocytochemical Localization. *Journal of*
2768 *Biological Chemistry* **276**(42), 39243–52.
- 2769 Gautron, J., E. Murayama, A. Vignal, M. Morisson, M. D. McKee, S. Réhault, V. Labas, et al.
2770 (2007). Cloning of Ovocalyxin-36, a Novel Chicken Eggshell Protein Related to
2771 Lipopolysaccharide-Binding Proteins, Bactericidal Permeability-Increasing Proteins, and
2772 Plunc Family Proteins. *Journal of Biological Chemistry* **282**(8), 5273–86.
- 2773 Geisert, R. D., Johns, D. N., Pfeiffer, C. A., Sullivan, R. M., Lucas, C. G., Simintiras, C. A., ... &
2774 Prather, R. S. (2023). Gene editing provides a tool to investigate genes involved in
2775 reproduction of pigs. *Molecular Reproduction and Development* **90**(7), 459-468.
- 2776 Ghorai, S.M., Priyam, M. (2018). Reptilia: Cellular Immunity in Reptiles: Perspective on
2777 Elements of Evolution. In: Cooper, E. (eds) *Advances in Comparative Immunology*.
2778 Springer, Cham. 773–91.

- 2779 Ghosh, J., C. M. Lun, A. J. Majeske, S. Sacchi, C. S. Schrankel, and L. C. Smith. (2011).
2780 Invertebrate Immune Diversity. *Developmental & Comparative Immunology* **35**(9), 959–
2781 74.
- 2782 Giansanti, F., M. F. Giardi, and D. Botti. (2006). Avian Cytokines-an Overview. *Current*
2783 *Pharmaceutical Design* **12**(24), 3083–99.
- 2784 Gibson, J. M., J. D. Aplin, A. White, and M. Westwood. (2001). Regulation of IGF
2785 Bioavailability in Pregnancy. *Molecular Human Reproduction* **7**(1),79-87
- 2786 Gilbert, S. F. (2010). Birds and Mammals: Early Development and Axis Formation.
2787 *Developmental Biology, 9th Ed. Sunderland, MA: Sinauer Associates, 287–322.*
- 2788 Girardi, G., Lingo, J. J., Fleming, S. D., & Regal, J. F. (2020). Essential role of complement in
2789 pregnancy: from implantation to parturition and beyond. *Frontiers in immunology* **11**,
2790 1681.
- 2791 Girling, J. E., A. Cree, and L. J. Guillette. (1997). Oviductal Structure in a Viviparous New
2792 Zealand Gecko, *Hoplodactylus maculatus*. *Journal of Morphology* **234**(1), 51–68.
- 2793 Girling, J. E. (2002). The Reptilian Oviduct: A Review of Structure and Function and Directions
2794 for Future Research. *Journal of Experimental Zoology* **293**(2), 141–70.
- 2795 Girling, J. E., and S. M. Jones. (2003). In Vitro Progesterone Production by Maternal and
2796 Embryonic Tissues during Gestation in the Southern Snow Skink (*Niveoscincus*
2797 *microlepidotus*). *General and Comparative Endocrinology* **133**(1), 100–108.

- 2798 Girling, J. E., A. Cree, and L. J. Jr. Guillette. (1998). Oviducal Structure in Four Species of
2799 Gekkonid Lizard Differing in Parity Mode and Eggshell Structure. *Reproduction,*
2800 *Fertility and Development Contraceptives* **10**(2),139-154.
- 2801 Gitlin, D., J. Kumate, J. Urrusti, and C. Morales. (1965). The Selectivity of the Human Placenta
2802 in the Transfer of Plasma Proteins from Mother to Fetus. *Obstetrical and Gynecological*
2803 *Survey* **20**(2), 217–20.
- 2804 Glazier, J. D., D. E. Atkinson, K. L. Thornburg, P. T. Sharpe, D. Edwards, R. D. H. Boyd, and C.
2805 P. Sibley. (1992). Gestational Changes in Ca²⁺ Transport across Rat Placenta and
2806 MRNA for Calbindin(9K) and Ca²⁺-ATPase. *American Journal of Physiology -*
2807 *Regulatory Integrative and Comparative Physiology* **262**, R930-R935
- 2808 González, Á., V. Rebmann, J. LeMaoult, P. A. Horn, E. D. Carosella, and E. Alegre. (2012). The
2809 Immunosuppressive Molecule HLA-G and Its Clinical Implications. *Critical Reviews in*
2810 *Clinical Laboratory Sciences* **49**(3), 63–84.
- 2811 Graham, S. P., R. L. Earley, C. Guyer, and M. T. Mendonça. (2011). Innate Immune
2812 Performance and Steroid Hormone Profiles of Pregnant versus Nonpregnant
2813 Cottonmouth Snakes (*Agkistrodon piscivorus*). *General and Comparative Endocrinology*
2814 **174**(3), 348–53.
- 2815 Grammatopoulos, D., G. N. Milton, and E. W. Hillhouse. (1994). The Human Myometrial CRH
2816 Receptor: G Proteins and Second Messengers. *Molecular and Cellular Endocrinology*
2817 **99**(2), 245–50.

2818 Grammatopoulos, D., E. W. Hillhouse, G. M. Stirrat, and S. A. Williams (1996). The Biological
2819 Activity of the Corticotropin-Releasing Hormone Receptor-Adenylate Cyclase Complex
2820 in Human Myometrium Is Reduced at the End of Pregnancy. *Journal of Clinical*
2821 *Endocrinology and Metabolism* **81**(2), 745–51.

2822 Gray, C. A., R. C. Burghardt, G. A. Johnson, F. W. Bazer, and T. E. Spencer. (2002). Evidence
2823 That Absence of Endometrial Gland Secretions in Uterine Gland Knockout Ewes
2824 Compromises Conceptus Survival and Elongation. *Reproduction-Cambridge* **124**(2),
2825 289–300.

2826 Gray, C. A., F. F. Bartol, B. J. Tarleton, A. A. Wiley, G. A. Johnson, F. W. Bazer, and T. E.
2827 Spencer. (2001). Developmental Biology of Uterine Glands. *Biology of Reproduction* **65**,
2828 1311–23.

2829 Grey, H. M. (1963). Phylogeny of the Immune Response: Studies on Some Physical Chemical
2830 and Serologic Characteristics of Antibody Produced in the Turtle. *The Journal of*
2831 *Immunology* **91**(6), 819–25.

2832 Griffith, O. W., J. U. van Dyke, and M. B. Thompson. (2013). No Implantation in an Extra-
2833 Uterine Pregnancy of a Placentotrophic Reptile. *Placenta* **34**(6), 510–11.

2834 Griffith, O. W., D. G. Blackburn, M. C. Brandley, J. U. van Dyke, C. M. Whittington, and M. B.
2835 Thompson. (2015). Ancestral State Reconstructions Require Biological Evidence to Test
2836 Evolutionary Hypotheses: A Case Study Examining the Evolution of Reproductive Mode
2837 in Squamate Reptiles. *Journal of Experimental Zoology* **324**(6), 493–503.

2838 Griffith, O. W., M. C. Brandley, K. Belov, and M. B. Thompson. (2016). Reptile Pregnancy Is
2839 Underpinned by Complex Changes in Uterine Gene Expression: A Comparative Analysis
2840 of the Uterine Transcriptome in Viviparous and Oviparous Lizards. *Genome Biology and*
2841 *Evolution* **8**(10), 3226–39.

2842 Griffith, O. W., M. C. Brandley, C. M. Whittington, K. Belov, and M. B. Thompson. (2017).
2843 Comparative Genomics of Hormonal Signaling in the Chorioallantoic Membrane of
2844 Oviparous and Viviparous Amniotes. *General and Comparative Endocrinology* **244**,19–
2845 29.

2846 Griffith, O. W., A. R. Chavan, S. Protopapas, J. Maziarz, R. Romero, and G. P. Wagner.
2847 (2017). Embryo Implantation Evolved from an Ancestral Inflammatory Attachment
2848 Reaction. *Proceedings of the National Academy of Sciences* **114**(32), E6566–75.

2849 Griffith, O. W., B. Ujvari, K. Belov, and M. B. Thompson. (2013). Placental Lipoprotein Lipase
2850 (LPL) Gene Expression in a Placentotrophic Lizard, *Pseudemoia entrecasteauxii*. *Journal*
2851 *of Experimental Zoology Part B: Molecular and Developmental Evolution* **320**(7): 465–
2852 70.

2853 Griffith, O. W., and G. P. Wagner. (2017). The Placenta as a Model for Understanding the Origin
2854 and Evolution of Vertebrate Organs. *Nature Ecology and Evolution* **1**(4).

2855 Griffith, O. W., Chavan, A. R., Pavlicev, M., Protopapas, S., Callahan, R., Maziarz, J., & Wagner,
2856 G. P. (2019). Endometrial recognition of pregnancy occurs in the grey short-tailed opossum
2857 (*Monodelphis domestica*). *Proceedings: Biological Sciences* **286**(1905), 1–9.

- 2858 Guarino, F. M., L. Paulesu, A. Cardone, L. Bellini, G. Ghiara, and F. Angelini. (1998).
2859 Endocrine Activity of the Corpus Luteum and Placenta during Pregnancy in *Chalcides*
2860 *chalcides* (Reptilia, Squamata). *General and Comparative Endocrinology* **111**(3), 261–
2861 70.
- 2862 Guillette, L. J. Jr, and R. E. Jones. 1980. Arginine Vasotocin-induced in Vitro Oviductal
2863 Contractions in *Anolis carolinensis*: Effect of Steroid Hormone Pretreatment in Vivo.
2864 *Journal of Experimental Zoology* **212**(1), 147–52.
- 2865 Guillette, L. J. Jr. (1992). Morphology of the Reproductive Tract in a Lizard Exhibiting Incipient
2866 Viviparity (*Sphenomorphus fragilis*) and Its Implications for the Evolution of the Reptilian
2867 Placenta. *Journal of Morphology* **212**(2), 163–73.
- 2868 Guillette, L. J. Jr., K. A. Bjorndal, A. B. Bolten, T. S. Gross, B. D. Palmer, B. E. Witherington,
2869 and J. M. Matter. (1991). Plasma Estradiol-17 β , Progesterone, Prostaglandin F, and
2870 Prostaglandin E2 Concentrations during Natural Oviposition in the Loggerhead Turtle
2871 (*Caretta caretta*). *General and Comparative Endocrinology* **82**(1), 121–30.
- 2872 Guillette, Louis L. J. Jr., V. Demarco, B. D. Palmer, and G. R. Masson. (1992). Effects of
2873 Arachidonic Acid, Prostaglandin F2, Prostaglandin E2, and Arginine Vasotocin on
2874 Induction of Birth in Viva and in Vitro in a Viviparous Lizard (*Sceloporus jarrovi*). *General*
2875 *and Comparative Endocrinology* **85**, 477–85.
- 2876 Guillette, L. J. Jr., S. L. Fox, and B. D. Palmer. (1989). Oviductal Morphology and Egg Shelling
2877 in the Oviparous Lizards *Crotaphytus collaris* and *Eumeces obsoletus*. *Journal of*
2878 *Morphology* **201**(2), 145–59.

- 2879 Guillette, L. J. Jr., and R. E. Jones. (1985). Ovarian, Oviductal, and Placental Morphology of the
2880 Reproductively Bimodal Lizard, *Sceloporus Aeneus*. *Journal of Morphology* **184**(1), 85–98.
- 2881 Gutsche, S., M. von Wolff, T. Strowitzki, and C. J. Thaler. (2003). Seminal Plasma Induces
2882 MRNA Expression of IL-1 β , IL-6 and LIF in Endometrial Epithelial Cells in Vitro.
2883 *Molecular Human Reproduction* **9**(12), 785–91.
- 2884 Hackmon, R., L. Pinnaduwege, J. Zhang, S. J. Lye, D. E. Geraghty, and C. E. Dunk. (2017).
2885 Definitive Class I Human Leukocyte Antigen Expression in Gestational Placentation: HLA-
2886 F, HLA-E, HLA-C, and HLA-G in Extravillous Trophoblast Invasion on Placentation,
2887 Pregnancy, and Parturition. *American Journal of Reproductive Immunology* **77**(6), 1–11.
- 2888 Hadi, H. A., C. A. Hodson, and D. Strickland. (1994). Premature Rupture of the Membranes
2889 between 20 and 25 Weeks' Gestation: Role of Amniotic Fluid Volume in Perinatal
2890 Outcome. *American Journal of Obstetrics and Gynecology* **170**(4), 1139–44.
- 2891 Haggarty P. (2002). Placental Regulation of Fatty Acid Delivery and Its Effect on Fetal Growth--
2892 a Review. *Placenta*. **23**, S28-38.
- 2893 Haider, S., and M. Knöfler. (2009). Human Tumour Necrosis Factor: Physiological and
2894 Pathological Roles in Placenta and Endometrium. *Placenta* **30**(2), 111–23.
- 2895 Haimovici, F., J. A. Hill, and D. J. Anderson. (1991). The Effects of Immunological Cytokines
2896 on Mouse Blastocyst Implantation in Vitro. *Biology of Reproduction* **44**, 69–75.

- 2897 Haluska, G. J., F. Z. Stanczyk, M. J. Cook, and M. J. Novy. (1987). Temporal Changes in
2898 Uterine Activity and Prostaglandin Response to RU486 in Rhesus Macaques in Late
2899 Gestation. *American Journal of Obstetrics and Gynecology* 157(6), 1487–95.
- 2900 Hamilton, R. M. G. (1986). The Microstructure of the Hen' s Egg Shell -A Short Review. *Food*
2901 *Structure* 5(1), 99–110.
- 2902 Han, H. I., S. H. Lee, E. J. Song, S. Lee, H. T. Cheong, B. K. Yang, and C. K. Park. (2016).
2903 Effect of Uterine Histotroph on Embryo Development in Pigs. *Journal of Embryo Transfer*
2904 31(3), 199–205.
- 2905 Hanna, J., D. Goldman-Wohl, Y. Hamani, I. Avraham, C. Greenfield, S. Natanson-Yaron, D.
2906 Prus, et al. (2006). Decidual NK Cells Regulate Key Developmental Processes at the
2907 Human Fetal-Maternal Interface. *Nature Medicine* 12(9), 1065–74.
- 2908 Hansen, V. L., L. S. Faber, A. A. Salehpoor, and R. D. Miller. (2017). A Pronounced Uterine
2909 Pro-Inflammatory Response at Parturition Is an Ancient Feature in Mammals. *Proceedings*
2910 *of the Royal Society* 284(1865), 20171694
- 2911 Hansen, V. L., F. D. Schilkey, and R. D. Miller. (2016). Transcriptomic Changes Associated
2912 with Pregnancy in a Marsupial, the Gray Short-Tailed Opossum *Monodelphis Domestica*.
2913 *PLoS ONE* 11(9), 1–25.
- 2914 Hardison, R. (1998). Hemoglobins from Bacteria to Man: Evolution of Different Patterns of
2915 Gene Expression. *The Journal of Experimental Biology* 1117, 1099–1117.

- 2916 Harrington, S., and T. W. Reeder. (2017). Rate Heterogeneity across Squamata, Misleading
2917 Ancestral State Reconstruction and the Importance of Proper Null Model Specification.
2918 *Journal of Evolutionary Biology* **30**(2), 313–25.
- 2919 Hedley, M. L., B. L. Drake, J. R. Head, P. W. Tucker, and J. Forman. (1989). Differential
2920 Expression of the Class I MHC Genes in the Embryo and Placenta during Midgestational
2921 Development in the Mouse. *The Journal of Immunology* **142**(11), 4046–53.
- 2922 Hempstock, J., T. Cindrova-Davies, E. Jauniaux, and G. J. Burton. (2004). Endometrial Glands
2923 as a Source of Nutrients, Growth Factors and Cytokines during the First Trimester of
2924 Human Pregnancy: A Morphological and Immunohistochemical Study. *Reproductive*
2925 *Biology and Endocrinology* **2**, 1–14.
- 2926 Hendrawan, K., C. M. Whittington, M. C. Brandley, K. Belov, and M. B. Thompson. (2017).
2927 The Regulation of Uterine Proinflammatory Gene Expression during Pregnancy in the Live-
2928 Bearing Lizard, *Pseudemoia entrecasteauxii*. *Journal of Experimental Zoology Part B:*
2929 *Molecular and Developmental Evolution* **328**(4), 334–46.
- 2930 Herbert, J., M. B. Thompson, and L. A. Lindsay. (2006). Calcium Transport across the Uterine
2931 Epithelium of Pregnant Lizards. *Herpetological Monographs* **20**(1), 1–63.
- 2932 Hernández-Díaz, N., R. Torres, and M. Patricia Ramírez-Pinilla. (2017). Proteomic Profile of
2933 Mabuya Sp. (Squamata: Scincidae) Ovary and Placenta During Gestation. *Journal of*
2934 *Experimental Zoology Part B: Molecular and Developmental Evolution* **328**(4), 371–89.
- 2935 Hernández-Hernández, A., A. B. Rodríguez-Navarro, J. Gómez-Morales, C. Jiménez-López, Y.
2936 Nys and J. Manuel García-Ruiz. (2008). Influence of Model Globular Proteins with

- 2937 Different Isoelectric Points on the Precipitation of Calcium Carbonate. *Crystal Growth &*
2938 *Design* **8**, 1495-1502.
- 2939 Hernández-Hernández, A., J. Gómez-Morales, A. B. Rodríguez-Navarro, J. Gautron, Y. Nys, and
2940 J. M. García-Ruiz. (2008). Identification of Some Active Proteins in the Process of Hen
2941 Eggshell Formation. *Crystal Growth and Design* **8**(12), 4330–39.
- 2942 Hernández-Hernández, A., M. L. Vidal, J. Gómez-Morales, A. B. Rodríguez-Navarro, V. Labas,
2943 J. Gautron, Y. Nys, and J. M. García Ruiz. (2008). Influence of Eggshell Matrix Proteins on
2944 the Precipitation of Calcium Carbonate (CaCO₃). *Journal of Crystal Growth* **310**(7–9),
2945 1754–59.
- 2946 Hertelendy, F., M. Yeh, and H. v. Biellier. (1974). Induction of Oviposition in the Domestic Hen
2947 by Prostaglandins. *General and Comparative Endocrinology* **22**(4), 529–31.
- 2948 Heulin, B. (1990). Étude Comparative de La Membrane Coquillère Chez Les Souches Ovipare et
2949 Vivipare Du Léopard Lacerta Vivipara. *Canadian Journal of Zoology*.
- 2950 Heulin, B., S. Ghielmi, N. Vogrin, Y. Surget-Groba, and C. P. Guillaume. (2002). Variation in
2951 Eggshell Characteristics and in Intrauterine Egg Retention between Two Oviparous Clades
2952 of the Lizard Lacerta Vivipara: Insight into the Oviparity-Viviparity Continuum in
2953 Squamates. *Journal of Morphology* **252**(3), 255–62.
- 2954 Heulin, B., J. R. Stewart, Y. Surget-Groba, P. Bellaud, and F. Jouan. (2005). Development of the
2955 Uterine Shell Glands During the Preovulatory and Early Gestation Periods in Oviparous and
2956 Viviparous Lacerta vivipara *Journal of Morphology* **266**(1), 80–93.

- 2957 Higashi, T., S. Tokuda, S. I. Kitajiri, S. Masuda, H. Nakamura, Y. Oda, and M. Furuse. (2013).
2958 Analysis of the 'angulin' Proteins LSR, ILDR1 and ILDR2 - Tricellulin Recruitment,
2959 Epithelial Barrier Function and Implication in Deafness Pathogenesis. *Journal of Cell*
2960 *Science* **126**(16), 3797.
- 2961 Hill, J. A. (1992). Cytokines Considered Critical in Pregnancy. *American Journal of*
2962 *Reproductive Immunology* **28**(3-4), 123–26.
- 2963 Hillhouse, E. W., Grammatopoulos D. K. (2001) Control of intracellular signalling by
2964 corticotropin-releasing hormone (CRH) in human myometrium. *Frontiers of Hormone*
2965 *Resesearch* 27:66 –74
- 2966 Hincke, M. T., J. Gautron, C. P. W. Tsang, M. D. McKee, and Y. Nys. (1999). Molecular
2967 Cloning and Ultrastructural Localization of the Core Protein of an Eggshell Matrix
2968 Proteoglycan, Ovocleidin-116. *Journal of Biological Chemistry* **274**(46), 32915–23.
- 2969 Hincke, M. T., Y. Nys, J. Gautron, A. B. Rodriguez-Navarro, K. Mann, and M. D. McKee.
2970 (2012). The Eggshell: Structure, Composition and Mineralization. *Frontiers in Bioscience*
2971 **17**(4), 1266–80.
- 2972 Hincke, M. T., O. Wellman-Labadie, M. D. McKee, J. Gautron, Y. Nys, and K. Mann. (2008).
2973 Biosynthesis and Structural Assembly of Eggshell Components. In Y. Mine (Eds.) *Egg*
2974 *Bioscience and Biotechnology* (pp. 97–128). Wiley-Interscience.
- 2975 Ho, S. M. (1987). Endocrinology of vitellogenesis. In D. O. Norris & R. E. Jones (Eds.)
2976 *Hormones and reproduction in fishes, amphibians, and reptiles* (pp. 145-169). Springer.

- 2977 Hodges, W. L. (2004). Evolution of Viviparity in Horned Lizards (Phrynosoma): Testing the
2978 Cold-Climate Hypothesis. *Journal of Evolutionary Biology* **17**(6), 1230–37.
- 2979 Hoenderop, J. G. J., B. Nilius, and R. J. M. Bindels. (2005). Calcium Absorption across
2980 Epithelia. *Physiological Reviews* **85**(1), 373–422.
- 2981 Hubrecht, A. A. W. (1910). Memoirs: the fetal membranes of the vertebrates. *Journal of Cell*
2982 *Science*. **2**, 177–188.
- 2983 Hughes, R. L. (1984). Structural Adaptations of the Eggs and the Fetal Membranes of
2984 Monotremes and Marsupials for Respiration and Metabolic Exchange. In: Seymour, R.S.
2985 (Eds.) *Respiration and Metabolism of Embryonic Vertebrates. Perspectives in vertebrate*
2986 *science* (pp. 389–421). Springer.
- 2987 Hunt, J. S., J. L. Pace, P. J. Morales, and C. Ober. (2003). Immunogenicity of the Soluble
2988 Isoforms of HLA-G. *Molecular Human Reproduction* **9**(11): 729–35.
- 2989 Hunt, J. S., M. G. Petroff, R. H. McIntire, and C. Ober. (2005). HLA-G and Immune Tolerance
2990 in Pregnancy. *The Federation of American Societies of Experimental Biology Journal* **19**(7):
2991 681–93.
- 2992 Husslein, P. (1984). The Importance of Oxytocin and Prostaglandins to the Mechanism of Labor
2993 in Humans. *Wiener Klinische Wochenschrift* **155**, 1–32.
- 2994 Hviid, T. V. F., S. Hylenius, A. Lindhard, and O. B. Christiansen. (2004) Association between
2995 Human Leukocyte Antigen-G Genotype and Success of in Vitro Fertilization and Pregnancy
2996 Outcome. *Tissue Antigens* **64**(1), 66–69.

2997 Iida, A., Hiroyuki N. A., Y. Someya, M. Inokuchi, T. A. Onuma, H. Yokoi, T. Suzuki, E. Hondo,
2998 and K. Sano. (2019) Mother-to-Embryo Vitellogenin Transport in a Viviparous Teleost
2999 *Xenotoca Eiseni*. *Proceedings of the National Academy of Sciences* **116**(44), 22359–65.

3000 Ikenouchi, J., M. Furuse, K. Furuse, H. Sasaki, Sa. Tsukita, and Sh. Tsukita. (2005). Tricellulin
3001 Constitutes a Novel Barrier at Tricellular Contacts of Epithelial Cells. *Journal of Cell*
3002 *Biology* **171**(6), 939–45.

3003 Ilicic, M., T. Butler, T. Zakar, and J. W. Paul. (2017). The Expression of Genes Involved in
3004 Myometrial Contractility Changes during Ex Situ Culture of Pregnant Human Uterine
3005 Smooth Muscle Tissue. *Journal of Smooth Muscle Research* **53**(1): 73–89.

3006 Ingram, G. A., and D. H. Molyneux. (1983). The Humoral Immune Response of the Spiny-
3007 Tailed Agamid Lizard (*Agama caudospinosum*) to Injection with *Leishmania* *Agamae*
3008 Promastigotes. *Veterinary Immunology and Immunopathology* **4**(4), 479–91.

3009 Iozzo, R. V., & L. Schaefer. (2015). Proteoglycan form and function: A comprehensive
3010 nomenclature of proteoglycans. *Matrix biology: Journal of the International Society for*
3011 *Matrix Biology* **42**, 11–55.

3012 Ishitani, A., N. Sageshima, N. Lee, N. Dorofeeva, K. Hatake, H. Marquardt, and D. E. Geraghty.
3013 (2003). Protein Expression and Peptide Binding Suggest Unique and Interacting Functional
3014 Roles for HLA-E, F, and G in Maternal-Placental Immune Recognition. *The Journal of*
3015 *Immunology* **171**(3), 1376–84.

3016 Jenkins, N. K., and K. Simkiss. (1968). The Calcium and Phosphate Metabolism of Reproducing
3017 Reptiles with Particular Reference to the Adder (*Vipera Berus*). *Comparative Biochemistry*
3018 *and Physiology* **26**(3).

3019 Jeong, J., A. U. Rao, J. Xu, S. L. Ogg, Y. Hathout, C. Fenselau, and I. H. Mather. (2009). The
3020 PRY/SPRY/B30.2 Domain of Butyrophilin 1A1 (BTN1A1) Binds to Xanthine
3021 Oxidoreductase. *Journal of Biological Chemistry* **284**(33), 22444–56.

3022 Jerez, A., and M. P. Ramírez-Pinilla. (2001). The Allantoplacenta of *Mabuya mabouya* (Sauria,
3023 Scincidae). *Journal of Morphology* **249**(2), 132–46.

3024 Ji, X., and W. G. Du. (2001). The Effects of Thermal and Hydric Environments on Hatching
3025 Success, Embryonic Use of Energy and Hatchling Traits in a Colubrid Snake, *Elaphe*
3026 *carinata*. *Comparative Biochemistry and Physiology - A Molecular and Integrative*
3027 *Physiology* **129**(2–3), 461–71.

3028 Ji, X., C. X. Lin, L. H. Lin, Q. B. Qiu, and Y. Du. (2007). Evolution of Viviparity in Warm-
3029 Climate Lizards: An Experimental Test of the Maternal Manipulation Hypothesis. *Journal*
3030 *of Evolutionary Biology* **20**(3), 1037–45.

3031 Jiang, B., Y. He, A. Elsler, S. Wang, J. N. Keating, J. Song, J., S. L. Kearns, and M. J. Benton
3032 (2023). Extended embryo retention and viviparity in the first amniotes. *Nature Ecology &*
3033 *Evolution* **7**, 1131-1140

3034 Johnston, H., I. Koukoulas, K. Jeyaseelan, A. Armugam, L. Earnest, R. Baird, N. Dawson, T.
3035 Ferraro, and E. M. Wintour. (2000). Ontogeny of Aquaporins 1 and 3 in Ovine Placenta and
3036 Fetal Membranes. *Placenta* **21**(1), 88–99.

- 3037 Jonchère, V., S. Rehault-Godbert, C. Hennequet-Antier, C. Cabau, V. Sibut, L. A. Cogburn, Y.
3038 Nys, and J. Gautron. (2010). Gene Expression Profiling to Identify Eggshell Proteins
3039 Involved in Physical Defense of the Chicken Egg. *BMC Genomics* **11**, 57.
- 3040 Jonchère, V., A. Brionne, J. Gautron, and Y. Nys. (2012). Identification of Uterine Ion
3041 Transporters for Mineralization Precursors of the Avian Eggshell. *BMC Physiology* **12**(10).
- 3042 Jones, R. E., and L. J. Guillette. (1982). Hormonal Control of Oviposition and Parturition in
3043 Lizards. *Herpetologica* **38**(1), 80–93.
- 3044 Jones, R. E., K. H. Lopez, C. H. Summers, and H. B. Austin. (1987). Seasonal Changes in the
3045 Effects of Arginine Vasotocin and Stretch on Anolis Uterine Contractions in Vitro. *Journal*
3046 *of Experimental Zoology* **242**(2), 233–39.
- 3047 Jonsson, A. M., M. Uzunel, C. Götherström, N. Papadogiannakis, and M. Westgren. (2008).
3048 Maternal Microchimerism in Human Fetal Tissues. *American Journal of Obstetrics and*
3049 *Gynecology* **198**(3), 325.e1-325.e6.
- 3050 Joosten, I., M. F. Sanders, and E. J. Hensen. (1991). Involvement of Major Histocompatibility
3051 Complex Class I Compatibility between Dam and Calf in the Aetiology of Bovine Retained
3052 Placenta. *Animal Genetics* **22**(6), 455–63.
- 3053 Kämmerer, U., L. Rieger, A. Honig, and E. Kämpgen. (2006). Characterization of Human
3054 Dendritic Cells at the Materno-Fetal Interface. In *Immunology of Pregnancy* 122–29.
3055 Springer.

3056 Kampmann, U., S. Knorr, J. Fuglsang, and P. Ovesen. (2019). Determinants of Maternal Insulin
3057 Resistance during Pregnancy: An Updated Overview. *Journal of Diabetes Research*.

3058 Kao, C. Y., and J. R. McCullough. (1975). Ionic Currents in the Uterine Smooth Muscle. *Journal*
3059 *of Physiology* **246**, 1–36.

3060 Karteris, E., D. Grammatopoulos, Y. Dai, K. B. Olah, T. B. Ghobara, A. Easton, and E. W.
3061 Hillhouse. (1998). The Human Placenta and Fetal Membranes Express the Corticotropin-
3062 Releasing Hormone Receptor 1 α (CRH-1 α) and the CRH-C Variant Receptor. *Journal of*
3063 *Clinical Endocrinology and Metabolism* **83**(4), 1376–79.

3064 Kawagoe, T., S. Sato, K. Matsushita, H. Kato, K. Matsui, Y. Kumagai, T. Saitoh, T. Kawai, O.
3065 Takeuchi, and S. Akira. (2008). Sequential Control of Toll-like Receptor–Dependent
3066 Responses by IRAK1 and IRAK2. *Nature Immunology* **9**(6), 684.

3067 Kayisli, U. A., B. Selam, O. Guzeloglu-Kayisli, R. Demir, and A. Arici. (2003). Human
3068 Chorionic Gonadotropin Contributes to Maternal Immunotolerance and Endometrial
3069 Apoptosis by Regulating Fas-Fas Ligand System. *The Journal of Immunology* **171**(5),
3070 2305–13.

3071 Kelly, R. W. (1995). Contraception: Immunosuppressive Mechanisms in Semen: Implications for
3072 Contraception. *Human Reproduction* **10**(7), 1686–93.

3073 Khosrotehrani, K., K. L. Johnson, S. Gu, H. Stroh, and D. W. Bianchi. (2005). Natural History of
3074 Fetal Cell Microchimerism during and Following Murine Pregnancy. *Journal of*
3075 *Reproductive Immunology* **66**, 1–12.

- 3076 Kieffer, T. E. C., A. Laskewitz, S. A. Scherjon, M. M. Faas, and J. R. Prins. (2019). Memory T
3077 Cells in Pregnancy. *Frontiers in Immunology* **10**(APR).
- 3078 King, A., T. D. Burrows, S. E. Hiby, J. M. Bowen, S. Joseph, S. Verma, P. B. Lim, et al. (2000).
3079 Surface Expression of HLA-C Antigen by Human Extravillous Trophoblast. *Placenta* **21**
3080 (4): 376–87.
- 3081 King, A., D. S. J. Allan, M. Bowen, S. J. Powis, S. Joseph, S. Verma, S. E. Hiby, A. J.
3082 Mcmichael, Y. Wai. Loke, and M. Braud. (2000). HLA-E Is Expressed on Trophoblast and
3083 Interacts with CD94 / NKG2 Receptors on Decidual NK Cells. *European Journal of*
3084 *Immunology* **30**(6), 1623–31.
- 3085 King, A., C. Birkby, and Y. W. Loke. (1989). Early Human Decidual Cells Exhibit NK Activity
3086 against the K562 Cell Line but Not against First Trimester Trophoblast. *Cellular*
3087 *Immunology* **118**(2), 337–44.
- 3088 King, B. F., and J. M. Wilson. (1983). A Fine Structural and Cytochemical Study of the Rhesus
3089 Monkey Yolk Sac: Endoderm and Mesothelium. *The Anatomical Record* **205**(2), 143–58.
- 3090 King, N. J. C., B. L. Drake, L. E. Maxwell, and J. C. Rodger. (1987). Class I Major
3091 Histocompatibility Complex Antigen Expression on Early Murine Trophoblast and Its
3092 Induction by Lymphokines in Vitro. II. The Role of Gamma Interferon in the Responses of
3093 Primary and Secondary Giant Cells. *Journal of Reproductive Immunology* **12**(1), 13–21.
- 3094 Klein, C., and M. H. T. Troedsson. (2011). Maternal Recognition of Pregnancy in the Horse: A
3095 Mystery Still to Be Solved. *Reproduction, Fertility and Development* **23**(8), 952–63.

3096 Klein, C. (2016). Journal of Equine Veterinary Science Maternal Recognition of Pregnancy in
3097 the Context of Equine Embryo Transfer. *Journal of Equine Veterinary Science* **41**, 22–28.

3098 Koo, T. H., H. Yang, B. S. An, K. C. Choi, S. H. Hyun, and E. B. Jeung. (2012). Calcium
3099 Transport Genes Are Differently Regulated in Maternal and Fetal Placenta in the Knockout
3100 Mice of Calbindin-D 9k and -D 28k. *Molecular Reproduction and Development* **79**(5), 346–
3101 55.

3102 Kovacs, C. S. (2015). Early Human Development Calcium, Phosphorus, and Bone Metabolism
3103 in the Fetus and Newborn. *Early Human Development* **91**(11). 623–28.

3104 Kovacs, C. S., B. Lanske, J. L. Hunzelman, J. Guo, A. C. Karaplis, and H. M. Kronenberg.
3105 (1996). Parathyroid Hormone-Related Peptide (PTHrP) Regulates Fetal-Placental Calcium
3106 Transport through a Receptor Distinct from the PTH/PTHrP Receptor. *Proceedings of the*
3107 *National Academy of Sciences* **93**(26), 15233–38.

3108 Kovats, S., E. K. Main, C. Librach, M. Stubblebine, J. Susan, R. Demars, J. Wang, et al. (1990).
3109 A Class I Antigen , HLA-G , Expressed in Human Trophoblasts *American Association for*
3110 *the Advancement of Science* **248**(4952), 220–23.

3111 Kuchling, G., and M. D. Hofmeyr. (2022). Too Hot to Nest? In a Hot Summer the Tortoise
3112 *Chersina angulata* Can Switch from Nesting to Facultative Viviparity. *Frontiers in Ecology*
3113 *and Evolution* **9**(Jan).

3114 Kumari, S. T. R., H. B.D. Sarkar, and T. Shivanandappa. (1992). Histological, Histochemical,
3115 and Biochemical Changes in the Annual Oviduct Cycle of the Agamid, *Calotes versicolor*.
3116 *Journal of Morphology* **211**(3): 295–306.

- 3117 Kuzmina, I. V. (2023). The yolk sac as the main organ in the early stages of animal embryonic
3118 development. *Frontiers in Physiology*, **14**, 1185286.
- 3119 Lafond, J., and L. Simoneau. (2006). Calcium Homeostasis in Human Placenta: Role of
3120 Calcium-Handling Proteins. *International Review of Cytology* **250**(06), 109–74.
- 3121 Lafontaine, L., P. Chaudhry, M. J. Lafleur, C. van Themsche, M. J. Soares, and E. Asselin.
3122 (2011). Transforming Growth Factor Beta Regulates Proliferation and Invasion of Rat
3123 Placental Cell Lines. *Biology of Reproduction* **84**(3), 553–59.
- 3124 Laird, M. K., M. B. Thompson, and C. M. Whittington. (2019). Facultative Oviparity in a
3125 Viviparous Skink (*Saiphos equalis*). *Biology Letters* **15**(4).
- 3126 Lakshminarayanan, R., E. O. Chi-Jin, X. J. Loh, R. M. Kini, and S. Valiyaveetil. (2005).
3127 Purification and Characterization of a Vaterite-Inducing Peptide, Pelovaterin, from the
3128 Eggshells of *Pelodiscus sinensis* (Chinese Soft-Shelled Turtle). *Biomacromolecules* **6**(3),
3129 1429–37.
- 3130 Lappas, M., and G. E. Rice. (2007). The Role and Regulation of the Nuclear Factor Kappa B
3131 Signalling Pathway in Human Labour. *Placenta* **28**(5–6), 543–56.
- 3132 Lappas, M., M. Permezel, H. M. Georgiou, and G. E. Rice. (2002). Nuclear Factor Kappa B
3133 Regulation of Proinflammatory Cytokines in Human Gestational Tissues in Vitro. *Biology*
3134 *of Reproduction* **67**(2), 668–73.
- 3135 Laurin, M. (2005). Embryo retention, character optimization, and the origin of the extra-
3136 embryonic membranes of the amniotic egg. *Journal of Natural History*. **39**, 3151–3161

- 3137 Larsson, A., D. Carlander, and M. Wilhelmsson. (1998). Antibody Response in Laying Hens
3138 with Small Amounts of Antigen. *Food and Agricultural Immunology* **10**(1), 29–36.
- 3139 Le Bouteiller, P., and Marie-Pierre Piccinni. (2008). Human NK Cells in Pregnant Uterus: Why
3140 There? *American Journal of Reproductive Immunology* **59**(5), 401–6.
- 3141 Le Roy, N., L. Stapane, J. Gautron, and M. T. Hincke. (2021). Evolution of the Avian Eggshell
3142 Biomineralization Protein Toolkit – New Insights from Multi-Omics. *Frontiers in Genetics*.
- 3143 Leadon, D. P., P. D. Rosedale, L. B. Jeffcott, and W. R. Allen. (1982). A Comparison of Agents
3144 for Inducing Parturition in Mares in the Pre-Viable and Premature Periods of Gestation.
3145 *Journal of Reproduction and Fertility* **32**, 597–602.
- 3146 Lee, M. S. Y., and P. Doughty. (1997). The Relationship between Evolutionary Theory and
3147 Phylogenetic Analysis. *Biological Reviews* **72**(4): 471–95.
- 3148 Lee, M. S. Y., and R. Shine. (1998). Reptilian Viviparity and Dollo’s Law. *Evolution* **52**(5):
3149 1441–50.
- 3150 Lee, S. Y., J. W. Anderson, G. L. Scott, and H. W. Mossman. (1983). Ultrastructure of the
3151 Placenta and Fetal Membranes of the Dog: II. The Yolk Sac. *American Journal of Anatomy*
3152 **166**(3), 313–27.
- 3153 Lefebvre, D. L., M. Piersanti, X. H. Bai, Z. Q. Chen, and S. J. Lye. (1995). Myometrial
3154 Transcriptional Regulation of the Gap Junction Gene, Connexin-43. *Reproduction, Fertility*
3155 *and Development* **7**(3), 603–11.

3156 Lefebvre, S., S. Berrih-Aknin, F. Adrian, P. Moreau, S. Poëa, L. Gourand, J. Dausset, E. D.
3157 Carosella, and P. Paul. (2001). A Specific Interferon (IFN)-Stimulated Response Element of
3158 the Distal HLA-G Promoter Binds IFN-Regulatory Factor 1 and Mediates Enhancement of
3159 This Nonclassical Class I Gene by IFN- β . *Journal of Biological Chemistry* **276**(9), 6133–
3160 39.

3161 Legendre, L. J., S. Choi, J. A. Clarke. (2022). The Diverse Terminology of Reptile Eggshell
3162 Microstructure and its Effect on Phylogenetic Comparative Analyses. *Journal of Anatomy*.
3163 **241**(3), 641-666.

3164 Leiphrakpam, P. D., P. P. Patil, N. Remmers, B. Swanson, P. M. Grandgenett, F. Qiu, F. Yu, P.
3165 Radhakrishnan. (2019). Role of keratan sulfate expression in human pancreatic cancer
3166 malignancy. *Scientific Reports* **9**, 9665.

3167 Lelong, C., M. Mathieu, and P. Favrel. (2000). Structure and Expression of MGDF, a New
3168 Member of the Transforming Growth Factor- β Superfamily in the Bivalve Mollusc
3169 *Crassostrea gigas*. *European Journal of Biochemistry* **267**(13), 3986–93.

3170 Li, X. H., A. H. Kishore, D. Dao, W. Zheng, C. A. Roman, and R. A. Word. (2010). A Novel
3171 Isoform of Microphthalmia-Associated Transcription Factor Inhibits IL-8 Gene Expression
3172 in Human Cervical Stromal Cells. *Molecular Endocrinology* **24**(8), 1512–28.

3173 Liabakk, N. B., E. Lien, A. Sundan, A. Sunde, R. Austgulen, and T. Espevik. (1993).
3174 Immunology: High Concentrations of the Soluble P55 Tumour Necrosis Factor Receptor in
3175 Human Seminal Plasma. *Human Reproduction* **8**(11), 1837–42.

- 3176 Lin, S. C., Y. C. Lo, and H. Wu. (2010). Helical Assembly in the MyD88-IRAK4-IRAK2
3177 Complex in TLR/IL-1R Signalling. *Nature* **465**(7300), 885–90.
- 3178 Lin, Y. P., and P. C. Singer. (2005). Inhibition of Calcite Crystal Growth by Polyphosphates.
3179 *Water Research* **39**(19), 4835–43.
- 3180 Lindau, R., J. Svensson-Arvelund, R. B. Mehta, D. Eklund, G. E. Lash, M C Jenmalm, and J
3181 Ernerudh. (2015). IL-34 at the Human Fetal–Maternal Interface. *Journal of Reproductive*
3182 *Immunology* **111**, 11–12.
- 3183 Lindegaard, M. L.S., G. Olivecrona, C. Christoffersen, D. Kratky, J. Hannibal, B. L. Petersen, R.
3184 Zechner, P. Damm, and L. B. Nielsen. (2005). Endothelial and Lipoprotein Lipases in
3185 Human and Mouse Placenta. *Journal of Lipid Research* **46**(11), 2339–46.
- 3186 Lindström, T. M., and P. R. Bennett. (2005). The Role of Nuclear Factor Kappa B in Human
3187 Labour. *Reproduction* **130**(5), 569–81.
- 3188 Linville, B. J., J. R. Stewart, T. W. Ecay, J. F. Herbert, S. L. Parker, and M. B. Thompson.
3189 (2010). Placental Calcium Provision in a Lizard with Prolonged Oviductal Egg Retention.
3190 *Journal of Comparative Physiology B: Biochemical, Systemic, and Environmental*
3191 *Physiology* **180**(2): 221–27.
- 3192 Liu, S., L. Diao, C. Huang, Y. Li, Y. Zeng, and J. Y.H. Kwak-Kim. (2017). The Role of
3193 Decidual Immune Cells on Human Pregnancy. *Journal of Reproductive Immunology* **124**,
3194 44–53.

- 3195 Lockwood, C. J. (2004). The Initiation of Parturition at Term. *Obstetrics and Gynecology Clinics*
3196 **31**(4), 935–47.
- 3197 Lourdais, O., Lorioux, S., Dupoué, A., Wright, C., & DeNardo, D. F. (2015). Embryonic water
3198 uptake during pregnancy is stage-and fecundity-dependent in the snake *Vipera aspis*.
3199 *Comparative Biochemistry and Physiology Part A: Molecular & Integrative Physiology*
3200 **189**, 102-106.
- 3201 Luu, K. C., G. Y. Nie, A. Hampton, G. Q. Fu, Y. X. Liu, and L. A. Salamonsen. (2004).
3202 Endometrial Expression of Calbindin (CaBP)-D28k but Not CaBP-D9k in Primates Implies
3203 Evolutionary Changes and Functional Redundancy of Calbindins at Implantation.
3204 *Reproduction* **128**(4), 433–41.
- 3205 Lynch, V. J., and G. P. Wagner. (2010). Did Egg-Laying Boas Break Dollo’s Law? Phylogenetic
3206 Evidence for Reversal to Oviparity in Sand Boas (*Eryx*: Boidae). *Evolution* **64**(1), 207–16.
- 3207 **Ma, L., Buckley, L. B., Huey, R. B., Du, W.-G., & Pincheira-Donoso, D.** (2018). A global test
3208 of the cold-climate hypothesis for the evolution of viviparity of squamate reptiles. *Global*
3209 *Ecology and Biogeography* **27**, 679–689.
- 3210 Mead, R., V. P. Eroschenko, D. R. Highfill. (1981). Effects of progesterone and estrogen on the
3211 histology of the oviduct of the garter snake, *Thamnophis elegans*. *Endocrinology* **45**(3),
3212 345-354.
- 3213 Madeja, Z., H. Yadi, R. Apps, S. Boulenouar, S. J. Roper, L. Gardner, A. Moffett, F. Colucci,
3214 and M. Hemberger. (2011). Paternal MHC Expression on Mouse Trophoblast Affects

3215 Uterine Vascularization and Fetal Growth. *Proceedings of the National Academy of*
3216 *Sciences* **108**(10), 4012–17.

3217 Makrigiannakis, A., M. Karamouti, P. Drakakis, D. Loutradis, and A. Antsaklis. (2008).
3218 Fetomaternal Immunotolerance. *American Journal of Reproductive Immunology* **60**(6),
3219 482–96.

3220 Manaster, I., and O. Mandelboim. (2010). The Unique Properties of Uterine NK Cells. *American*
3221 *Journal of Reproductive Immunology* **63**(6), 434–44.

3222 Mann, K., B. Maček, and J. V. Olsen. (2006). Proteomic Analysis of the Acid-Soluble Organic
3223 Matrix of the Chicken Calcified Eggshell Layer. *Proteomics* **6**(13), 3801–10.

3224 Marchalonis, J. J., E. H. M. Ealey, and E. Diener. (1969). Immune Response of the Tuatara,
3225 *Sphenodon punctatum*. *Australian Journal of Experimental Biology and Medical Science*
3226 **47**(3), 367–80.

3227 Marillat, R. I. E., O. Cases, K. T. Nguyen-Ba-Charvet, M. Tessier-Lavigne, C. Sotelo, and A.
3228 Che. (2002). Spatiotemporal Expression Patterns of Slit and Robo Genes in the Rat Brain
3229 *Journal of Comparative Neurology* **442**(2), 130–55.

3230 Masuhiro, K., E. Nishino, N. Matsuzaki, T. Kameda, T. Tanigushi, T. Takagi, F. Saji, and O.
3231 Tanizawa. 1990. Trophoblast-Derived Interleukin-6 (IL-6) Regulates Human Chorionic
3232 Gonadotropin Release through IL-6 Receptor on Human Trophoblasts. *The Journal of*
3233 *Clinical Endocrinology & Metabolism* **71**(2), 436–41.

- 3234 Mathies, T., and R. M. Andrews. (1999). Determinants of Embryonic Stage at Oviposition in the
3235 Lizard *Urosaurus ornatus*. *Physiological and Biochemical Zoology* **72**(6), 645–55.
- 3236 Mathies, T., and R. M. Andrews. (2000). Does Reduction of the Eggshell Occur Concurrently
3237 with or Subsequent to the Evolution of Viviparity in Phrynosomatid Lizards? *Biological*
3238 *Journal of the Linnean Society* **71**(719).
- 3239 Matschke, K., L. D. Silva-Azevedo, R. Hlushchuk, V. Djonov, and O. Baum. (2006). Annexins
3240 as Cell-Type-Specific Markers in the Developing Chicken Chorionallantoic Membrane.
3241 *Cell and Tissue Research* **323** (3): 395–404.
- 3242 Matzinger, P. (2007). Friendly and Dangerous Signals: Is the Tissue in Control? *Nature*
3243 *Immunology* **8**(1), 11–13.
- 3244 McLean, M., and R. Smith. (2001). Corticotrophin-Releasing Hormone and Human Parturition.
3245 *Reproduction* **121**(4), 493–501.
- 3246 Medawar, P. B. (1991). The Nobel Lectures in Immunology: The Nobel Prize for Physiology or
3247 Medicine, 1960. *Scandinavian Journal of Immunology* **33**(4), 337–44.
- 3248 Medawar, P. B. (1953). Some Immunological and Endocrinological Problems Raised by the
3249 Evolution of Viviparity in Vertebrates. In *Symposium for the Society of Experimental*
3250 *Biology* **7**, 320–37.
- 3251 Medeiros, D. M., and J. G. Crump. (2012). New Perspectives on Pharyngeal Dorsoventral
3252 Patterning in Development and Evolution of the Vertebrate Jaw. *Developmental Biology*
3253 **371**(2), 121–135.

- 3254 Mendelson, C. R. (2009). Minireview: Fetal-Maternal Hormonal Signaling in Pregnancy and
3255 Labor. *Molecular Endocrinology* **23**(7), 947–54.
- 3256 Mendelson, C. R., and J. C. Condon. (2005). New Insights into the Molecular Endocrinology of
3257 Parturition. *Journal of Steroid Biochemistry and Molecular Biology* **93**, 113–19.
- 3258 Mercado-Simmen, R. C., B. Goodwin, M. S. Ueno, S. Y. Yamamoto, and G. D. Bryant-
3259 Greenwod. (1982). Relaxin Receptors in the Myometrium of the Pig. *Biology of*
3260 *Reproduction* **26**, 120–28.
- 3261 Mercer, L. J., L. G. Brown, R. E. Petres, and R. H. Messer. (1984). A Survey of Pregnancies
3262 Complicated by Decreased Amniotic Fluid. *American Journal of Obstetrics and*
3263 *Gynecology* **149**(3), 355–61.
- 3264 Mesiano, S., E. C. Chan, J. T. Fitter, K. Kwek, G. Yeo, and R. Smith. (2002). Progesterone
3265 Withdrawal and Estrogen Activation in Human Parturition Are Coordinated by
3266 Progesterone Receptor an Expression in the Myometrium. *Journal of Clinical*
3267 *Endocrinology and Metabolism* **87**(6), 2924–30.
- 3268 Mesiano, S., Y. Wang, and E. R. Norwitz. (2011). Progesterone Receptors in the Human
3269 Pregnancy Uterus: Do They Hold the Key to Birth Timing? *Reproductive Sciences* **18**(1), 6–
3270 19.
- 3271 Metcalfe, J., and M. K. Stock. (1993). Oxygen Exchange in the Chorioallantoic Membrane,
3272 Avian Homologue of the Mammalian Placenta. *Placenta* **14**(6): 605–13.

- 3273 Miele, L., E. Cordella-Miele, and A. B. Mukherjee. (1987). Uteroglobin: Structure, Molecular
3274 Biology, and New Perspectives on Its Function as a Phospholipase A2 Inhibitor. *Endocrine*
3275 *Reviews* **8**(4), 474–90.
- 3276 Mikhailov, K. E. (1997). Fossil and Recent Eggshell in Amniotic Vertebrates: Fine Structure,
3277 Comparative Morphology and Classification Article. *Special Papers in Palaeontology* **56**.
- 3278 Mikšík, I., A. Eckhardt, P. Sedláková, and K. Mikulikova. (2007). Proteins of Insoluble Matrix
3279 of Avian (*Gallus gallus*) Eggshell. *Connective Tissue Research* **48**(1), 1–8.
- 3280 Mikšík, I., P. Sedláková, K. Lacinová, S. Pataridis, and A. Eckhardt. (2010). Determination of
3281 Insoluble Avian Eggshell Matrix Proteins. *Analytical and Bioanalytical Chemistry* **397**(1):
3282 205–14.
- 3283 Moffett, A., and Y. W. Loke. (2004). The Immunological Paradox of Pregnancy: A Reappraisal.
3284 *Placenta* **25**(1), 1–8.
- 3285 Moffett, A., F. Colucci. (2014). Uterine NK Cells: Active Regulators at the Maternal-Fetal
3286 Interface. *The Journal of Clinical Investigation* **124**(5), 1872–79.
- 3287 Moffett, A., and C. Loke. (2006). Immunology of Placentation in Eutherian Mammals. *Nature*
3288 *Reviews Immunology* **6**(8), 584–94.
- 3289 Moffett-King, A. (2002). Natural Killer Cells and Pregnancy. *Nature Reviews Immunology* **2**(9):
3290 656–63.
- 3291 Mold, J. E., and J. M. McCune. (2011). At the Crossroads between Tolerance and Aggression
3292 Revisiting the ‘Layered Immune System’ Hypothesis. *Chimerism* **2**(2), 35–41.

- 3293 Mold, J. E., J. Michaëlsson, T. D. Burt, M. O. Muench, K. P. Beckerman, M. P. Busch, T. H.
3294 Lee, D. F. Nixon, and J. M. McCune. (2008). Maternal Alloantigens Promote the
3295 Development of Tolerogenic Fetal Regulatory T Cells in Utero. *Science* **322**(5907),1562–
3296 65.
- 3297 Mold, J. E., S. Venkatasubrahmanyam, T. D. Burt, J. Michaëlsson, J. M. Rivera, S. A. Galkina,
3298 K. Weinberg, C. A. Stoddart, and J. M. McCune. (2010). Fetal and Adult Hematopoietic
3299 Stem Cells Give Rise to Distinct T Cell Lineages in Humans. *Science* **330**, 1695–1700.
- 3300 Mor, G., I. Cardenas, V. Abrahams, and S. Guller. (2011). Inflammation and Pregnancy: The
3301 Role of the Immune System at the Implantation Site. *Annals of the New York Academy of*
3302 *Sciences* **1221**(1), 80–87.
- 3303 Morales, P., J. Ricardo, J. Paganini, and P. Pontarotti. (2017). Convergent Evolution of the
3304 Adaptive Immune Response in Jawed Vertebrates and Cyclostomes: An Evolutionary
3305 Biology Approach Based Study. *Developmental and Comparative Immunology* **75**, 120–26.
- 3306 Moreau, P., F. Adrian-Cabestre, C. Menier, V. Guiard, L. Gourand, J. Dausset, E. D. Carosella,
3307 and P. Paul. (1999). IL-10 Selectively Induces HLA-G Expression in Human Trophoblasts
3308 and Monocytes. *International Immunology* **11**(5), 803–11.
- 3309 Mossman, H. W. (1987). *Vertebrate Fetal Membranes: Comparative Ontogeny and Morphology,*
3310 *Evolution, Phylogenetic Significance, Basic Functions, Research Opportunities.* United
3311 States, Rutgers University Press.
- 3312 Mossman, H. W. (1991). Classics Revisited: Comparative Morphogenesis of the Fetal
3313 Membranes and Accessory Uterine Structures. *Placenta* **12**(1), 1-5.

- 3314 Motani, R., D-y. Jian, A. Tintori, O. Rieppel, G-b. Chen. (2014). Terrestrial Origin of Viviparity
3315 in Mesozoic Marine Reptiles Indicated by Early Triassic Embryonic Fossils. *PloS ONE*
3316 **9**(2).
- 3317 Mueller, A., J. Siemer, S. Schreiner, H. Koesztner, I. Hoffmann, H. Binder, M. W. Beckmann,
3318 and R. Dittrich. (2006). Role of Estrogen and Progesterone in the Regulation of Uterine
3319 Peristalsis: Results from Perfused Non-Pregnant Swine Uteri. *Human Reproduction* **21**(7),
3320 1863–68.
- 3321 Müller, V., R. J. de Boer, S. Bonhoeffer, and E. Szathmáry. (2018). An Evolutionary Perspective
3322 on the Systems of Adaptive Immunity. *Biological Reviews* **93**(1), 505–28.
- 3323 Mundkur, R., and H. B. Devaraj Sarkar. (1982). Localization of Some Enzymes Involved in
3324 Steroid Metabolism in the Oviduct of the Skink, *Mabuya carinata*. *Current Science* **51**(5),
3325 254–55.
- 3326 Munoz-Suano, A., A. B. Hamilton, and A. G. Betz. (2011). Gimme Shelter: The Immune System
3327 during Pregnancy. *Immunological Reviews* **241**(1), 20–38.
- 3328 Murphy, B. F., M. C. Brandley, C. R. Murphy, and M. B. Thompson. (2012). Morphology and
3329 Development of the Placentae in *Eulamprus quoyii* Group Skinks (Squamata: Scincidae).
3330 *Journal of Anatomy* **220**(5), 454–71.
- 3331 Murphy, B. F., S. L. Parker, C. R. Murphy, and M. B. Thompson. (2010). Angiogenesis of the
3332 Uterus and Chorioallantois in the Eastern Water Skink *Eulamprus quoyii*. *Journal of*
3333 *Experimental Biology* **213**(19), 3340–47.

- 3334 Murphy, B. F., and M. B. Thompson. (2011). A Review of the Evolution of Viviparity in
3335 Squamate Reptiles: The Past, Present and Future Role of Molecular Biology and Genomics.
3336 *Journal of Comparative Physiology B: Biochemical, Systemic, and Environmental*
3337 *Physiology* **181**(5), 575–94.
- 3338 Murphy, B. F., M. B Thompson, and K. Belov. (2009). Evolution of Viviparity and the Maternal
3339 Immune System: Major Histocompatibility Complex (MHC) Class I Genes in Skinks.
3340 *Orbit: University of Sydney Undergraduate Research Journal* **1**(1).
- 3341 Muzio, M., J. Ni, P. Feng, and V. M. Dixit. (1997). IRAK (Pelle) Family Member IRAK-2 and
3342 MyD88 as Proximal Mediators of IL- 1 Signaling. *Science* **278**(5343), 1612–15.
- 3343 Narbaitz, R., S. Kacew, and L. Sitwell. (1981). Carbonic Anhydrase Activity in the Chick
3344 Embryo Chorioallantois: A Regional Distribution and Vitamin D Regulation. *Journal of*
3345 *Embryology and Experimental Morphology* **65**, 127–37.
- 3346 Neill, W. T. (1964). Viviparity in Snakes: Some Ecological and Zoogeographical Considerations.
3347 *The American Naturalist* **98**(898), 35–55.
- 3348 Nelson, J. L. (2012). The Otherness of Self: Microchimerism in Health and Disease. *Trends in*
3349 *Immunology* **33**(8), 421–27.
- 3350 Norell, M. A., J. Wiemann, M. Fabbri, C. Yu, C. A. Marsicano, A. Moore-Nall, D. J. Varricchio,
3351 D. Pol, and D. K. Zelenitsky. (2020). The first dinosaur egg was soft. *Nature* **583**, 406-410.

- 3352 Noy, E. B., M. K. Scott, S. V. H. Grommen, K. A. Robert, and B. De Groef. (2017). Molecular
3353 Cloning and Tissue Distribution of Crh and Pomc mRNA in the Fat-Tailed Dunnart
3354 (*Sminthopsis crassicaudata*), an Australian Marsupial. *Gene* **627**, 26–31.
- 3355 Nys, Y., J. Zawadzki, J. Gautron, and A. D. Mills. (1991). Whitening of Brown-Shelled Eggs:
3356 Mineral Composition of Uterine Fluid and Rate of Protoporphyrin Deposition. *Poultry*
3357 *Science* **70**(5), 1236–45.
- 3358 Nys, Y., J. Gautron, J. M. Garcia-Ruiz, and M. T. Hincke. (2004). Avian Eggshell
3359 Mineralization: Biochemical and Functional Characterization of Matrix Proteins. *Comptes*
3360 *Rendus - Palevol* **3**(6-7), 549–62.
- 3361 Olson, D. M., and F. Hertelendy. (1983). Avian Shell Gland Contractility: Interaction of PGF₂
3362 Alpha and Arginine Vasotocin with Ca²⁺. *The American Journal of Physiology* **244**(3), 50–
3363 57.
- 3364 Olson, D. M., K. Shimada, and R. J. Etches. (1986). Prostaglandin Concentrations in Peripheral
3365 Plasma and Ovarian and Uterine Plasma and Tissue in Relation to Oviposition in Hens.
3366 *Biology of Reproduction* **35**(5), 1140–46.
- 3367 Olson, D. M. (2003). The Role of Prostaglandins in the Initiation of Parturition. *Best Practice &*
3368 *Research Clinical Obstetrics & Gynaecology* **17**(5), 717–30.
- 3369 Opazo, J. C., F. G. Hoffmann, and J. F. Storz. (2008). Genomic Evidence for Independent
3370 Origins of β-like Globin Genes in Monotremes and Therian Mammals. *Proceedings of the*
3371 *National Academy of Sciences* **105**(5), 1590–95.

3372 Origgi, F. C., P. A. Klein, K. Mathes, S. Blahak, R. E. Marschang, S. J. Tucker, and E. R.
3373 Jacobson. (2001). Enzyme-Linked Immunosorbent Assay for Detecting Herpesvirus
3374 Exposure in Mediterranean Tortoises (Spur-Thighed Tortoise [*Testudo graeca*] and
3375 Hermann's Tortoise [*Testudo hermanni*]). *Journal of Clinical Microbiology* **39**(9), 3156–63.

3376 Ortega Brown, E., S. A. Sundstrom, B. S. Komm, Z. Yi, C. Teuscher, and C. R. Lyttle. (1990).
3377 Progesterone Regulation of Estradiol-Induced Rat Uterine Secretory Protein, Complement
3378 C3. *Biology of Reproduction* **42**(4), 713–19.

3379 Ostrovsky, A. N. (2013). From Incipient to Substantial: Evolution of Placentotrophy in a Phylum
3380 of Aquatic Colonial Invertebrates. *Evolution* **67**(5), 1368–82.

3381 Ott, T. L., M. M. Kamat, S. Vasudevan, D. H. Townson, and J. L. Pate. (2014). Maternal
3382 Immune Responses to Conceptus Signals during Early Pregnancy in Ruminants. *Animal*
3383 *Reproduction* **11**(3), 237–45.

3384 Owen, R. D. (1945). Immunogenetic Consequences of Vascular Anastomoses between Bovine
3385 Twins. *Science* **102**(2651), 400–401.

3386 Packard, G. C., C. R. Tracy, and J. J. Roth. (1977). The Physiological Ecology of Reptilian Eggs
3387 and Embryos, and the Evolution of Viviparity within the Class Reptilia. *Biological Reviews*
3388 *of the Cambridge Philosophical Society* **52**(1), 71–105.

3389 Packard, G. C. (1991). Physiological and Ecological Importance of Water to Embryos of
3390 Oviparous Reptiles. In D. C. Deeming, M. W. J Ferguson (Eds.), *Egg Incubation: Its Effects*
3391 *on Embryonic Development in Birds and Reptiles*. (pp. 213-228). Cambridge: Cambridge
3392 University Press.

- 3393 Packard, G. C., and M. J. Packard. (1980). Evolution of the Cleidoic Egg among Reptilian
3394 Antecedents of Birds. *Integrative and Comparative Biology* **20**(2), 351–62.
- 3395 Packard, M. J. (1994). Patterns of Mobilization and Deposition of Calcium in Embryos of
3396 Oviparous, Amniotic Vertebrates. *Israel Journal of Zoology* **40**(3–4), 481–92.
- 3397 Packard, M. J., and L. D. Lohmiller. (2002). Mineral Status of Embryos of Domestic Fowl
3398 Following Exposure in Vivo to the Carbonic Anhydrase Inhibitor Acetazolamide.
3399 *Comparative Biochemistry and Physiology - A Molecular and Integrative Physiology*
3400 **132**(2), 257–65.
- 3401 Packard, M. J., and V. G. DeMarco. (1991). Eggshell Structure and Formation in Eggs of
3402 Oviparous Reptiles. In D. C. Deeming, M. W. J Ferguson (Eds.), *Egg Incubation: Its Effects*
3403 *on Embryonic Development in Birds and Reptiles*. (pp. 53-69). Cambridge: Cambridge
3404 University Press.
- 3405 Packard, M. J., and G. C. Packard. (1984). Comparative Aspects of Calcium Metabolism in
3406 Embryonic Reptiles and Birds. *Respiration and Metabolism of Embryonic Vertebrates*,
3407 155–79.
- 3408 Packard, M. J., G. C. Packard, J. D. Miller, M. E. Jones, and W. H. N. Gutzke. (1985). Calcium
3409 Mobilization, Water Balance, and Growth in Embryos of the Agamid Lizard *Amphibolurus*
3410 *barbatus*. *Journal of Experimental Zoology* **235**(3), 349–57.
- 3411 Palmer, B. D., V. G. Demarco, and L. J. Guillette. (1993). Oviductal Morphology and Eggshell
3412 Formation in the Lizard, *Sceloporus woodi*. *Journal of Morphology* **217**(2), 205–17.

- 3413 Park, J. S., C. W. Park, C. J. Lockwood, and E. R. Norwitz. (2005). Role of Cytokines in Preterm
3414 Labor and Birth. *Minerva Ginecologica* **57**(4), 349–66.
- 3415 Parker, S. L., and R. M. Andrews. (2006). Evolution of Viviparity in Sceloporine Lizards: In
3416 Utero Po₂ as a Developmental Constraint during Egg Retention. *Physiological and*
3417 *Biochemical Zoology* **79**(3), 581–92.
- 3418 Parker, S. L., F. Manconi, C. R. Murphy, and M. B. Thompson. (2010). Uterine and Placental
3419 Angiogenesis in the Australian Skinks, *Ctenotus taeniolatus*, and *Saiphos equalis*.
3420 *Anatomical Record* **293**(5), 829–38.
- 3421 Pashen, R. L., and W. R. Allen. (1979). The Role of the Fetal Gonads and Placenta in Steroid
3422 Production, Maintenance of Pregnancy and Parturition in the Mare. *Journal of*
3423 *Reproduction and Fertility* **27**, 499.
- 3424 Paulesu, L., R. Romagnoli, M. Marchetti, M. Cintorino, P. Ghiara, F. M. Guarino, and G. Ghiara.
3425 (1995). Cytokines in the Viviparous Reproduction of Squamate Reptiles: Interleukin-1 α
3426 (IL-1 α) and IL-1 β in Placental Structures of a Skink. *Placenta* **16**(2), 193–205.
- 3427 Paulesu, L. (1997). Cytokines in Mammalian Reproduction and Speculation about Their Possible
3428 Involvement in Nonmammalian Viviparity. *Microscopy Research and Technique* **38**(1-2),
3429 188–94.
- 3430 Paulesu, L., E. Bigliardi, E. Paccagnini, F. Ietta, C. Cateni, C. P. Guillaume, and B. Heulin.
3431 (2005). Cytokines in the Oviparity/Viviparity Transition: Evidence of the Interleukin-1
3432 System in a Species with Reproductive Bimodality, the Lizard *Lacerta vivipara*. *Evolution*
3433 *and Development* **7**(4), 282–88.

- 3434 Paulesu, L., S. Jantra, F. Ietta, R. Brizzi, and E. Bigliardi. (2008). Interleukin-1 in Reproductive
3435 Strategies. *Evolution and Development* **10**(6), 778–88.
- 3436 Paulesu, L., R. Romagnoli, and E. Bigliardi. (2005). Materno-Fetal Immunotolerance: Is
3437 Interleukin-1 a Fundamental Mediator in Placental Viviparity? *Developmental and*
3438 *Comparative Immunology* **29**(5), 409–15.
- 3439 Peck, A., and E. D. Mellins. (2010). Plasticity of T-Cell Phenotype and Function: The T Helper
3440 Type 17 Example. *Immunology* **129**(2), 147–53.
- 3441 Petersdorf, E. W., T. A. Gooley, M. Malkki, A. P. Bacigalupo, A. Cesbron, E. Du Toit, G.
3442 Ehninger, et al. (2014). HLA-C Expression Levels Define Permissible Mismatches in
3443 Hematopoietic Cell Transplantation. *Blood* **124**(26), 3996–4003.
- 3444 Petraglia, F., G. C. Garuti, B. De Ramundo, S. Angioni, A. R. Genazzani, and L. M. Bilezikjian.
3445 (1990). Mechanism of Action of Interleukin-1 β in Increasing Corticotropin-Releasing
3446 Factor and Adrenocorticotropin Hormone Release from Cultured Human Placental Cells.
3447 *American Journal of Obstetrics and Gynecology* **163**(4), 1307–12.
- 3448 Picariello, O., G. Ciarcia, and F. Angelini. (1989). The Annual Cycle of Oviduct in *Tarentola m.*
3449 *mauritanica* (Reptilia Gekkonidae). *Amphibia-Reptilia* **10**, 371–86.
- 3450 **Pincheira-Donoso, D., Jara, M., Reaney, A., García-Roa, R., Saldarriaga-Córdoba, M., and**
3451 **Hodgson, D. J.** (2017). Hypoxia and hypothermia as rival agents of selection driving the
3452 evolution of viviparity in lizards. *Global Ecology and Biogeography* **26**, 1238–1246.

- 3453 Piñeiro, G., Ferigolo, J., Meneghel, M. and Laurin, M. (2012). The oldest known amniotic
3454 embryos suggest viviparity in mesosaurs. *Historical Biology*, **24**(6), 620-630.
- 3455 Pines, M., V. Knopov, and A. Bar. (1995). Involvement of Osteopontin in Egg Shell Formation
3456 in the Laying Chicken. *Matrix Biology* **14**(9), 765–71.
- 3457 Podhalicz-Dzięgielewska, M., T. Rotkiewicz, T. Janowski, S. Zduńczyk, and A. Raś. (2000).
3458 Histological Findings in Placentomes of Cows with Retained Placenta. *Medycyna*
3459 *Weterynaryjna* **56**(6), 392–94.
- 3460 Pough, F. H. (1980). Blood Oxygen Transport and Delivery in Reptiles. *Integrative and*
3461 *Comparative Biology* **20**(1), 173–85.
- 3462 Pradeu, T., E. Vitanza (2011). Critique of the Self-Nonself Theory. In E. Vitanza (Eds.), *The*
3463 *Limits of the Self: Immunology and Biological Identity*. (pp. 85-130). Oxford University
3464 Press.
- 3465 Putnam, C. D., D. W. Brann, R. C. Kolbeck, and V. B. Mahesh. (1991). Inhibition of Uterine
3466 Contractility by Progesterone and Progesterone Metabolites: Mediation by Progesterone and
3467 Gamma Amino Butyric Acid(A) Receptor Systems. *Biology of Reproduction* **45**(2), 266–72.
- 3468 Pye, G. W., D. R. Brown, M. F. Nogueira, K. A. Vliet, T. R. Schoeb, E. R. Jacobson, and R. A.
3469 Bennett. (2001). Experimental Inoculation of Broad-Nosed Caimans (*Caiman latirostris*)
3470 and Siamese Crocodiles (*Crocodylus siamensis*) with *Mycoplasma alligatoris*. *Journal of*
3471 *Zoo and Wildlife Medicine* **32**(2), 196–201.

3472 **Pyron, R. A. 2015. Advancing perspectives on parity-mode evolution. *Journal of***
3473 *Experimental Zoology (Molecular and Developmental Evolution)* 324(6), 562–563.

3474 Pyron, R. A., and F. T. Burbrink. (2014). Early Origin of Viviparity and Multiple Reversions to
3475 Oviparity in Squamate Reptiles. *Ecology Letters* **17**(1), 13–21.

3476 Qualls, C. P. (1996). Influence of the Evolution of Viviparity on Eggshell Morphology in the
3477 Lizard, *Lerista bougainvillii*. *Journal of Morphology* **228**(2), 119–25.

3478 Rajagopalan, S., Y. T. Bryceson, S. P. Kuppusamy, D. E. Geraghty, A. van der Meer, I. Joosten,
3479 and E. O. Long. (2006). Activation of NK Cells by an Endocytosed Receptor for Soluble
3480 HLA-G. *PLoS Biology* **4**(1).

3481 Rajagopalan, S., and E. O. Long. (2012). KIR2DL4 (CD158d): An Activation Receptor for
3482 HLA-G. *Frontiers in Immunology* **3**, 1–6.

3483 Ramírez-Pinilla, M. P. (2006). Placental Transfer of Nutrients during Gestation in an Andean
3484 Population of the Highly Matrotrophic Lizard Genus *Mabuya* (Squamata: Scincidae).
3485 *Herpetological Monographs* **20**, 194–204.

3486 Ramírez-Pinilla, M. P., E. D. Rueda, and E. Stashenko. (2011). Transplacental Nutrient Transfer
3487 during Gestation in the Andean Lizard *Mabuya Sp.* (Squamata, Scincidae). *Journal of*
3488 *Comparative Physiology B: Biochemical, Systemic, and Environmental Physiology* **181**(2),
3489 249–68.

3490 Ramsay, T. G., J. Karousis, M. E. White, and C. K. Wolvertson. (1991). Fatty Acid Metabolism
3491 by the Porcine Placenta. *Journal of Animal Science* **69**(9), 3645–54.

- 3492 Ramsdell, F., and A. Y. Rudensky. (2020). Foxp3: A Genetic Foundation for Regulatory T Cell
3493 Differentiation and Function. *Nature Immunology* **21**(7), 708–9.
- 3494 **Rao, A., Fernández, M. S., Cölfen, H., & Arias, J. L.** (2015). Distinct effects of avian egg
3495 derived anionic proteoglycans on the early stages of calcium carbonate
3496 mineralization. *Crystal Growth & Design* **15**(5), 2052-2056.
- 3497 Rapacz-Leonard, A., M. Leonard, M. Chmielewska-Krzesińska, K. Paździor-Czapula, and T.
3498 Janowski. (2018). Major Histocompatibility Complex Class I in the Horse (*Equus caballus*)
3499 Placenta during Pregnancy and Parturition. *Placenta* **74**, 36–46.
- 3500 Ravanos, K., T. Dagklis, S. Petousis, C. Margioulas-Siarkou, Y. Prapas, and N. Prapas. (2015).
3501 Factors Implicated in the Initiation of Human Parturition in Term and Preterm Labor: A
3502 Review. *Gynecological Endocrinology* **31**(9), 679–83.
- 3503 Rawn, S. M., and J. C. Cross. (2008). The Evolution, Regulation, and Function of Placenta-
3504 Specific Genes. *Annual Review of Cell and Developmental Biology* **24**, 159–81.
- 3505 Rebmann, V., A. Busemann, M. Lindemann, and H. Grosse-Wilde. (2003). Detection of HLA-
3506 G5 Secreting Cells. *Human Immunology* **64**(11), 1017–24.
- 3507 Rebmann, V., F. Da Silva Nardi, B. Wagner, and P. A. Horn. (2014). HLA-G as a Tolerogenic
3508 Molecule in Transplantation and Pregnancy. *Journal of Immunology Research*. **2014**,
3509 297073.

3510 Recknagel H, and K.R. Elmer. Differential reproductive investment in co-occurring oviparous
3511 and viviparous common lizards (*Zootoca vivipara*) and implications for life-history trade-
3512 offs with viviparity (2019). *Oecologia* **190**(1), 85-98.

3513 Recknagel, H., M. Carruthers, A. A. Yurchenko, M. Nokhbatolfoghahai, N. A. Kamenos, M. M.
3514 Bain, and K. R. Elmer. (2021a). The Functional Genetic Architecture of Egg-Laying and
3515 Live-Bearing Reproduction in Common Lizards. *Nature Ecology & Evolution*. **5**, 1546–
3516 1556

3517 **Recknagel, H., N.A. Kamenos, and K.R. Elmer.** (2021b). Evolutionary origins of viviparity
3518 consistent with palaeoclimate and lineage diversification. *Journal of Evolutionary Biology*
3519 **34**, 1167–1176.

3520 Recknagel, H., N. A. Kamenos, and K. R. Elmer. (2018). Common Lizards Break Dollo’s Law
3521 of Irreversibility: Genome-Wide Phylogenomics Support a Single Origin of Viviparity and
3522 Re-Evolution of Oviparity. *Molecular Phylogenetics and Evolution* **127**, 579–88.

3523 Reiber, M. A., and D. E. Conner. (1995). Effect of Mating Activity on the Ability of Salmonella
3524 Enteritidis to Persist in the Ovary and Oviduct of Chickens. *Avian Diseases*. **39**(2), 323–27.

3525 Reiber, M. A., D. E. Conner, and S. F. Bilgili. (1995). Salmonella Colonization and Shedding
3526 Patterns of Hens Inoculated via Semen. *Avian Diseases*. **39**(2), 317–22.

3527 Reynolds, L. P., J. S. Caton, D. A. Redmer, A. T. Grazul-Bilska, K. A. Vonnahme, P. P.
3528 Borowicz, J. S. Luther, J. M. Wallace, G. Wu, and T. E. Spencer. 2006. Evidence for
3529 Altered Placental Blood Flow and Vascularity in Compromised Pregnancies. *Journal of*
3530 *Physiology* **572**(1), 51–58.

- 3531 Ribatti, D. 2015. Peter Brian Medawar and the Discovery of Acquired Immunological Tolerance.
3532 *Immunology Letters* **167**(2), 63–66.
- 3533 Ribatti, D., A. Frigeri, B. Nico, G. P. Nicchia, M. De Giorgis, L. Roncali, and M. Svelto. (2002).
3534 Aquaporin-1 Expression in the Chick Embryo Chorioallantoic Membrane. *Anatomical*
3535 *Record* **268**(2), 85–89.
- 3536 Rieger, L. (2002). Th1- and Th2-like Cytokine Production by First Trimester Decidual Large
3537 Granular Lymphocytes Is Influenced by HLA-G and HLA-E. *Molecular Human*
3538 *Reproduction* **8**(3), 255–61.
- 3539 Rimer, J., I. R. Cohen, and N. Friedman. (2014). Do All Creatures Possess an Acquired Immune
3540 System of Some Sort? *BioEssays* **36**(3), 273–81.
- 3541 Risau, W. (1997). Mechanisms of Angiogenesis. *Nature* **386**.
- 3542 Roberts, C. T., and W. G. Breed. (1996). Variation in Ultrastructure of Mucoïd Coat and Shell
3543 Membrane Secretion of a Dasyurid Marsupial. *Reproduction, Fertility and Development* **8**
3544 (4), 645–48.
- 3545 Roberts, C. T., W. G. Breed, and G. Mayrhofer. (1994). Origin of the Oocyte Shell Membrane of
3546 a Dasyurid Marsupial: An Immunohistochemical Study. *Journal of Experimental Zoology*
3547 **270**(3), 321–31.
- 3548 Roberts, C. T., and W. G. Breed. (1994). Placentation in the Dasyurid Marsupial, *Sminthopsis*
3549 *Crassicaudata*, the Fat-Tailed Dunnart, and Notes on Placentation of the Didelphid,
3550 Placentation in the Dasyurid Marsupial, *Sminthopsis crassicaudata*, the Fat-Tailed Dunnart,

- 3551 and Notes on placentation of the didelphid, *Monodelphis domestica*. *Journal of*
3552 *Reproduction and Fertility* **100**, 105–13.
- 3553 Robinson, B. G., J. L. Arbiser, R. L. Emanuel, and J. A. Majzoub. (1989). Species-Specific
3554 Placental Corticotropin Releasing Hormone Messenger RNA and Peptide Expression.
3555 *Molecular and Cellular Endocrinology* **62**(2), 337–41.
- 3556 Rodriguez-Martinez, H., F. Saravia, M. Wallgren, E. A. Martinez, L. Sanz, J. Roca, J. M.
3557 Vazquez, and J. J. Calvete. (2010). Spermadhesin PSP-I/PSP-II Heterodimer Induces
3558 Migration of Polymorphonuclear Neutrophils into the Uterine Cavity of the Sow. *Journal of*
3559 *Reproductive Immunology* **84**(1), 57–65.
- 3560 Rodríguez-Navarro, A. B., P. Marie, Y. Nys, M. T. Hincke, and J. Gautron. (2015). Amorphous
3561 Calcium Carbonate Controls Avian Eggshell Mineralization: A New Paradigm for
3562 Understanding Rapid Eggshell Calcification. *Journal of Structural Biology* **190**(3), 291–
3563 303.
- 3564 Romagnoli, R., C. Cateni, F. M. Guarino, E. Bigliardi, and L. R. Paulesu. (2003). Potential Role
3565 of Interleukin-1 at the Peri-Ovulation Stage in a Species of Placental Viviparous Reptile, the
3566 Three-Toed Skink, *Chalcides chalcides* (Squamata: Scincidae). *Reproductive Biology and*
3567 *Endocrinology* **1**, 1–6.
- 3568 Romer, A. S. (1957). Origin of the amniote egg. *The Scientific Monthly* **85**, 57–63.
- 3569 Romero, R., D. T. Brody, E. Oyarzun, M. Mazor, Y. K. Wu, J. C. Hobbins, and S. K. Durum.
3570 (1989). Infection and Labor: III. Interleukin-1: A Signal for the Onset of Parturition.
3571 *American Journal of Obstetrics and Gynecology* **160**(5), 1117–23.

- 3572 Romero, R., M. Mazor, F. Brandt, W. Sepulveda, C. Avila, D. B. Cotton, and C. A. Dinarello.
3573 (1992). Interleukin-1 α and Interleukin-1 β in Preterm and Term Human Parturition.
3574 *American Journal of Reproductive Immunology* **27**(3-4), 117–23.
- 3575 Rose-Martel, M., J. Du, and M. T. Hincke. (2012). Proteomic Analysis Provides New Insight
3576 into the Chicken Eggshell Cuticle. *Journal of Proteomics* **75**(9), 2697–2706.
- 3577 Ross, G. T. (1979). Human Chorionic Gonadotropin and Maternal Recognition of Pregnancy.
3578 *Maternal Recognition of Pregnancy* **64**.
- 3579 Rothchild, I. (2003). The Yolkless Egg and the Evolution of Eutherian Viviparity. *Biology of*
3580 *Reproduction* **68**(2), 337–57.
- 3581 Rothwell, L., J. R. Young, R. Zoorob, C. A. Whittaker, P. Hesketh, A. Archer, A. L. Smith, and
3582 P. Kaiser. (2004). Cloning and Characterization of Chicken IL-10 and Its Role in the
3583 Immune Response to *Eimeria Maxima*. *The Journal of Immunology* **173**(4), 2675–82.
- 3584 Rouas-Freiss, N., R. M. Gonçalves, C. Menier, J. Dausset, and E. D. Carosella. (1997). Direct
3585 Evidence to Support the Role of HLA-G in Protecting the Fetus from Maternal Uterine
3586 Natural Killer Cytolysis. *Proceedings of the National Academy of Sciences* **94**(21), 11520–
3587 25.
- 3588 Roussev, R. G., B. Acacio, S. C. Ng, and C. B. Coulam. (2008). Duration of Intralipid’s
3589 Suppressive Effect on NK Cell’s Functional Activity. *American Journal of Reproductive*
3590 *Immunology* **60**(3), 258–63.

- 3591 Rowe, J. H., J. M. Ertelt, L. Xin, and S. S. Way. (2012). Pregnancy Imprints Regulatory Memory
3592 That Sustains Anergy to Fetal Antigen. *Nature* **490**(7418), 102–6.
- 3593 Rzasas, J. (1978). Effects of Arginine Vasotocin and Prostaglandin E1 on the Hen Uterus.
3594 *Prostaglandins* **16**(3), 357–72.
- 3595 Saad, A. H., and S. El Deeb. (1990). Immunological Changes during Pregnancy in the
3596 Viviparous Lizard, *Chalcides ocellatus*. *Veterinary Immunology and Immunopathology*
3597 **25**(3): 279–86.
- 3598 Saito, S., A. Nakashima, T. Shima, and M. Ito. (2010). Th1/Th2/Th17 and Regulatory T-Cell
3599 Paradigm in Pregnancy. *American Journal of Reproductive Immunology* **63**(6), 601–10.
- 3600 Samuel, C. A., and J. S. Perry. (1972). The Ultrastructure of Pig Trophoblast Transplanted to an
3601 Ectopic Site in the Uterine Wall. *Journal of Anatomy* **113**(Pt 1), 139.
- 3602 Sarkar, S., N. K. Sarkar, and B. R. Maiti. (1995). Histological and Functional Changes of
3603 Oviductal Endometrium during Seasonal Reproductive Cycle of the Soft-shelled Turtle,
3604 *Lissemys punctata punctata*. *Journal of Morphology* **224**(1), 1–14.
- 3605 Satterfield, M. C., K. A. Dunlap, K. Hayashi, R. C. Burghardt, T. E. Spencer, and F. W. Bazer.
3606 (2007). Tight and Adherens Junctions in the Ovine Uterus: Differential Regulation by
3607 Pregnancy and Progesterone. *Endocrinology* **148**(8), 3922–31.
- 3608 Schiffman, J. S., and P. L. Ralph. (2022). System Drift and Speciation. *Evolution* **76** (2), 236–51.

- 3609 Schjenken, J. E., and S. A. Robertson. (2014). Seminal Fluid and Immune Adaptation for
3610 Pregnancy - Comparative Biology in Mammalian Species. *Reproduction in Domestic*
3611 *Animals* **49**, 27–36.
- 3612 Schumacher, A., and Zenclussen, A. C. (2015). The Paternal Contribution to Fetal Tolerance.
3613 *Advances in experimental medicine and biology* **868**, 211–225.
- 3614 Schwaha, T., M. Moosbrugger, M. Walzl, and A. N. Ostrovsky. (2019). First Ultrastructural
3615 Evidence of Placental Nutrition in a Ctenostome Bryozoan: Example of *Amathia*
3616 *verticillata*. *Zoomorphology* **138**(2), 221–32.
- 3617 Seavey, M., and T. R. Mosmann. (2006). Paternal Antigen-Bearing Cells Transferred during
3618 Insemination Do Not Stimulate Anti-Paternal CD8 + T Cells: Role of Estradiol in Locally
3619 Inhibiting CD8 + T Cell Responses. *The Journal of Immunology* **177**(11), 7567–78.
- 3620 Sellens, M. H., E. J. Jenkinson, and W. D. Billington. (1978). Major Histocompatibility Complex
3621 and Non-Major Histocompatibility Complex Antigens on Mouse Ectoplacental Cone and
3622 Placental Trophoblastic Cells. *Transplantation* **25**(4), 173–79.
- 3623 Shadrix, C. A., D. R. Crotzer, S. L. McKinney, and J. R. Stewart. (1994). Embryonic Growth and
3624 Calcium Mobilization in Oviposited Eggs of the Scincid Lizard, *Eumeces fasciatus*. *Copeia*
3625 **2**, 493.
- 3626 Shaw, G., and M. B. Renfree. (2001). Fetal Control of Parturition in Marsupials. *Reproduction,*
3627 *Fertility and Development* **13**(8), 653–59.

- 3628 Shen, X. X., D. Liang, J. Z. Wen, and P. Zhang. (2011). Multiple Genome Alignments Facilitate
3629 Development of NPCL Markers: A Case Study of Tetrapod Phylogeny Focusing on the
3630 Position of Turtles. *Molecular Biology and Evolution* **28**(12), 3237–52.
- 3631 Shine, R. (1983). Reptilian Viviparity in Cold Climates: Testing the Assumptions of an
3632 Evolutionary Hypothesis. *Oecologia* **57**(3), 397–405.
- 3633 Shine, R., and J. J. Bull. (1979). The Evolution of Live-Bearing in Lizards and Snakes. *The*
3634 *American Naturalist* **113**(6), 905–23.
- 3635 Shine, R., and L. J. Guillette. (1988). The Evolution of Viviparity in Reptiles: A Physiological
3636 Model and Its Ecological Consequences. *Journal of Theoretical Biology* **132**(1), 43–50.
- 3637 Shine, R., and M. B. Thompson. (2006). Did Embryonic Responses to Incubation Conditions
3638 Drive the Evolution of Reproductive Modes in Squamate Reptiles. *Herpetological*
3639 *Monographs* **20**(2006), 186–93.
- 3640 Shynlova, O., P. Tsui, A. Dorogin, and S. J. Lye. (2008). Monocyte Chemoattractant Protein-1
3641 (CCL-2) Integrates Mechanical and Endocrine Signals That Mediate Term and Preterm
3642 Labor. *The Journal of Immunology* **181**(2), 1470–79.
- 3643 Simkiss, K. (1980). Water and Ionic Fluxes inside the Egg. *Integrative and Comparative Biology*
3644 **20**(2), 385–93.
- 3645 Simmonds, C. S., G. Karsenty, A. C. Karaplis, and C. S. Kovacs. (2010). Parathyroid Hormone
3646 Regulates Fetal-Placental Mineral Homeostasis. *Journal of Bone and Mineral Research*
3647 **25**(3), 594–605.

- 3648 Sipes, S. L., M. V. Medaglia, D. L. Stabley, C. S. DeBruyn, M. S. Alden, V. Catenacci, and C. P.
3649 Landel. (1996). A New Major Histocompatibility Complex Class Ib Gene Expressed in the
3650 Mouse Blastocyst and Placenta. *Immunogenetics* **45**(2), 108–20.
- 3651 Sites, J. W., T. W. Reeder, and J. J. Wiens. (2011). Phylogenetic Insights on Evolutionary
3652 Novelties in Lizards and Snakes: Sex, Birth, Bodies, Niches, and Venom. *Annual Review of*
3653 *Ecology, Evolution, and Systematics* **42**(1), 227–44.
- 3654 Slater, D., W. Dennes, R. Sawdy, V. Allport, and P. Bennett. (1999). Expression of Cyclo-
3655 Oxygenase Types-1 and-2 in Human Fetal Membranes throughout Pregnancy. *Journal of*
3656 *Molecular Endocrinology* **22**(2), 125–30.
- 3657 Slater, D. M., L. C. Berger, R. Newton, G. E. Moore, and P. R. Bennett. (1995). Expression of
3658 Cyclooxygenase Types 1 and 2 in Human Fetal Membranes at Term. *American Journal of*
3659 *Obstetrics and Gynecology* **172**, 77–82.
- 3660 Slater, M., and C. R. Murphy. (1999). Thrombospondin Is Sequentially Expressed and Then De-
3661 Expressed during Early Pregnancy in the Rat Uterus. *Histochemical Journal* **31**(7), 471–75.
- 3662 **Smith, H. M. (1975) Grist for the mills of herpetophiles in Mexico. *Bulletin of the Maryland***
3663 *Herpetological Society* **11**, 40-44.
- 3664 Smith, S. A., C. Austin, and R. Shine. (2001). A Phylogenetic Analysis of Variation in
3665 Reproductive Mode within an Australian Lizard (*Saiphos equalis*, Scincidae). *Biological*
3666 *Journal of the Linnean Society* **74**, 131-139.

- 3667 Soloff, M. S., Y. J. Jeng, M. G. Izban, M. Sinha, B. A. Luxon, S. J. Stammes, and S. K. England.
3668 (2011). Effects of Progesterone Treatment on Expression of Genes Involved in Uterine
3669 Quiescence. *Reproductive Sciences* **18**(8), 781–97.
- 3670 Song, G., D. W. Bailey, K. A. Dunlap, R. C. Burghardt, T. E. Spencer, F. W. Bazer, and G. A.
3671 Johnson. (2010). Cathepsin B, Cathepsin L, and Cystatin C in the Porcine Uterus and
3672 Placenta: Potential Roles in Endometrial/Placental Remodeling and in Fluid-Phase
3673 Transport of Proteins Secreted by Uterine Epithelia across Placental Areolae. *Biology of*
3674 *Reproduction* **82**(5), 854–64.
- 3675 Sooranna, S. R., Y. Lee, L. U. Kim, A. R. Mohan, P. R. Bennett, and Mark R. Johnson. (2004).
3676 Mechanical Stretch Activates Type 2 Cyclooxygenase via Activator Protein-1 Transcription
3677 Factor in Human Myometrial Cells. *Molecular Human Reproduction* **10**(2), 109–13.
- 3678 Sorbera, L., G. Giannoukos, and I. Callard. (1988). Progesterone and Relaxin Inhibit Turtle
3679 Myometrium. *American Society of Zoologists Conference Proceedings* Lawrence, KS.
- 3680 Speake, B. K., J. F. Herbert, and M. B. Thompson. (2004). Evidence for Placental Transfer of
3681 Lipids during Gestation in the Viviparous Lizard, *Pseudemoia entrecasteauxii*.
3682 *Comparative Biochemistry and Physiology - A Molecular and Integrative Physiology*
3683 **139**(2): 213–20.
- 3684 Spencer, T. E., and F. W. Bazer. (2004). Uterine and Placental Factors Regulating Conceptus
3685 Growth in Domestic Animals. *Journal of Animal Science* **82**, E4–13.
- 3686 Srivastava, M. D., J. Lippes, and B. I. Sahai Srivastava. (1996). Cytokines of the Human
3687 Reproductive Tract. *American Journal of Reproductive Immunology* **36**(3), 157–66.

3688 Stadtmauer, D. J., and G. P. Wagner. (2020a). Cooperative Inflammation: The Recruitment of
3689 Inflammatory Signaling in Marsupial and Eutherian Pregnancy. *Journal of Reproductive*
3690 *Immunology* **137**, 102626.

3691 ———. (2020b). The Primacy of Maternal Innovations to the Evolution of Embryo
3692 Implantation. *Integrative and Comparative Biology* **60**(3), 742–52.

3693 Starck, J. M. (2021). Morphology of the Avian Yolk Sac. *Journal of Morphology*. **282** (7), 959-
3694 972

3695 Staub, R., and J. Emberton. (2002). *Eryx jayakari* (Arabian Sand Boa) Reproduction.
3696 *Herpetological Review* **33**, 214.

3697 Stein, K., E. Prondvai, T. Huang, J-M. Baele, P. M. Sander, and R.Reisz (2019) Structure and
3698 evolutionary implications of the earliest (Sinemurian, Early Jurassic) dinosaur eggs and
3699 eggshells. *Scientific Reports* **9**, 4424.

3700 Stern, P. L., N. Beresford, C. I. Friedman, V. C. Stevens, J. M. Risk, and P. M. Johnson. (1987).
3701 Class I-like MHC Molecules Expressed by Baboon Placental Syncytiotrophoblast. *The*
3702 *Journal of Immunology* **138**(4), 1088–91.

3703 Stevens, A. M., W. M. McDonnell, M. E. Mullarkey, J. M. Pang, W. Leisenring, and J. L.
3704 Nelson. (2004). Liver Biopsies from Human Females Contain Male Hepatocytes in the
3705 Absence of Transplantation. *Laboratory Investigation* **84**(12), 1603–9.

3706 Stewart, J. R. (1989). Facultative Placentotrophy and the Evolution of Squamate Placentation:
3707 Quality of Eggs and Neonates in *Virginia striatula*. *The American Naturalist* **133**(1), 111–
3708 37.

3709 ———. (2013). Fetal Nutrition in Lecithotrophic Squamate Reptiles: Toward a Comprehensive
3710 Model for Evolution of Viviparity and Placentation. *Journal of Morphology* **274**(7), 824–
3711 43.

3712 Stewart, J. R., and M. B. Thompson. (1993). A Novel Pattern of Embryonic Nutrition in a
3713 Viviparous Reptile. *Journal of Experimental Biology* **174**(1), 97–108.

3714 Stewart, J. R., T. W. Ecy, C. P. Garland, S. P. Fregoso, E. K. Price, J. F. Herbert, and M. B.
3715 Thompson. (2009). Maternal Provision and Embryonic Uptake of Calcium in an Oviparous
3716 and a Placentotrophic Viviparous Australian Lizard (Lacertilia: Scincidae). *Comparative*
3717 *Biochemistry and Physiology. Part A, Molecular & Integrative Physiology* **153**(2), 202–8.

3718 Stewart, J. R., and R. E. Castillo. (1984). Nutritional Provision of the Yolk of Two Species of
3719 Viviparous Reptiles. *Physiological Zoology* **57**(4), 377–83.

3720 Stewart, J. R., and D. G. Blackburn. (1988). Reptilian Placentation: Structural Diversity and
3721 Terminology. *Copeia* **1988** (4), 839.

3722 Stewart, J. R., and T. W. Ecy. (2010). Patterns of Maternal Provision and Embryonic
3723 Mobilization of Calcium in Oviparous and Viviparous. *Herpetological Conservation and*
3724 *Biology* **5**(2), 341–59.

- 3725 Stewart, J. R., T. W. Ecaj, and D. G. Blackburn. (2004). Sources and Timing of Calcium
3726 Mobilization during Embryonic Development of the Corn Snake, *Pantherophis guttatus*.
3727 *Comparative Biochemistry and Physiology - A Molecular and Integrative Physiology*
3728 **139**(3), 335–41.
- 3729 Stewart, J. R., T. W. Ecaj, and B. Heulin. (2009). Calcium Provision to Oviparous and
3730 Viviparous Embryos of the Reproductively Bimodal Lizard *Lacerta (Zootoca) vivipara*.
3731 *Journal of Experimental Biology* **212**(16), 2520–24.
- 3732 Stewart, J. R., T. W. Ecaj, B. Heulin, S. P. Fregoso, and B. J. Linville. (2011). Developmental
3733 Expression of Calcium Transport Proteins in Extraembryonic Membranes of Oviparous and
3734 Viviparous *Zootoca vivipara* (Lacertilia, Lacertidae). *Journal of Experimental Biology*
3735 **214**(18), 2999–3004.
- 3736 Stewart, J. R., A. N. Mathieson, T. W. Ecaj, J. F. Herbert, S. L. Parker, and M. B. Thompson.
3737 (2010). Uterine and Eggshell Structure and Histochemistry in a Lizard with Prolonged
3738 Uterine Egg Retention (Lacertilia, Scincidae, *Saiphos*). *Journal of Morphology* **271**(11),
3739 1342–51.
- 3740 Stewart, J. R., and M. B. Thompson. (2009). Parallel Evolution of Placentation in Australian
3741 Scincid Lizards. *Journal of Experimental Zoology Part B: Molecular and Developmental*
3742 *Evolution* **312**(6), 590–602.
- 3743 Stinnett, H. K., J. R. Stewart, T. W. Ecaj, R. A. Pyles, J. F. Herbert, and M. B. Thompson.
3744 (2011). Placental Development and Expression of Calcium Transporting Proteins in the

- 3745 Extraembryonic Membranes of a Placentotrophic Lizard. *Journal of Morphology* **273**(3),
3746 347–59.
- 3747 Stouffer, R. L., and J. D. Hennebold. (2015). Structure, Function, and Regulation of the Corpus
3748 Luteum. In *Knobil and Neill's Physiology of Reproduction: Two-Volume Set*. (Vol. 1, pp.
3749 1023-1076). Elsevier Inc.
- 3750 Suzuki, Y., C. S. Kovacs, H. Takanaga, J. B. Peng, C. P. Landowski, and M. A. Hediger. (2008).
3751 Calcium Channel TRPV6 Is Involved in Murine Maternal-Fetal Calcium Transport. *Journal*
3752 *of Bone and Mineral Research* **23**(8), 1249–56.
- 3753 Svensson-Arvelund, J., R. B. Mehta, R. Lindau, E. Mirrasekhian, H. Rodriguez-Martinez, G.
3754 Berg, G. E. Lash, M. C. Jenmalm, and J. Ernerudh. (2021). The Human Fetal Placenta
3755 Promotes Tolerance against the Semiallogeneic Fetus by Inducing Regulatory T Cells and
3756 Homeostatic M2 Macrophages. *The Journal of Immunology* **194**(4).
- 3757 Swain, R., and S. M. Jones. (2000). Facultative Placentotrophy: Half-Way House or Strategic
3758 Solution? *Comparative Biochemistry and Physiology - A Molecular and Integrative*
3759 *Physiology* **127**(4), 441–51.
- 3760 Swain, R., and S. M. Jones. (1997). Maternal-Fetal Transfer of 3H-Labelled Leucine in the
3761 Viviparous Lizard *Niveoscincus metallicus* (Scincidae: Lygosominae). *Journal of*
3762 *Experimental Zoology* **277**(2), 139–45.
- 3763 Sykes, L., D. A. MacIntyre, T. Ghee Teoh, and P. R. Bennett. (2014). Anti-Inflammatory
3764 Prostaglandins for the Prevention of Preterm Labour. *Reproduction* **148**(2).

- 3765 Szekeres-Bartho, J., S. Šučurović, and B. Mulac-Jeričević. (2018). The Role of Extracellular
3766 Vesicles and PIBF in Embryo-Maternal Immune-Interactions. *Frontiers in Immunology* **9**,
3767 2890.
- 3768 Takahashi, T., H. Ogawa, R. Inaba, and M. Kawashima. (2004). Changes in Prostaglandin F
3769 Concentration in the Uterus (Shell Gland) of the Hen Oviduct in Relation to Oviposition
3770 and Estrogen. *Poultry Science* **83**(10), 1745–49.
- 3771 Tamizian, O., and S. Arulkumaran. (2004). Uterine Contractions. *The Management of Labour*.
3772 Orient Blackswan, **86**.
- 3773 Tartakovsky, B., and E. Ben-Yair. (1991). Cytokines Modulate Preimplantation Development
3774 and Pregnancy. *Developmental Biology* **146**(2), 345–52.
- 3775 Tayade, C., G. P. Black, Y. Fang, and A. Croy. (2006). Differential Gene Expression in
3776 Endometrium, Endometrial Lymphocytes, and Trophoblasts during Successful and Abortive
3777 Embryo Implantation. *The Journal of Immunology* **176**, 148–56.
- 3778 Teles, A., A. Schumacher, M. C. Kühnle, N. Linzke, C. Thuere, P. Reichardt, C. E. Tadokoro, G.
3779 J. Hämmerling, and A. C. Zenclussen. (2013). Control of Uterine Microenvironment by
3780 Foxp3+ Cells Facilitates Embryo Implantation. *Frontiers in Immunology* **4**, 158.
- 3781 Terzidou, V. (2007). Biochemical and Endocrinological Preparation for Parturition. *Best
3782 Practice and Research: Clinical Obstetrics and Gynaecology* **21**(5), 729–56.
- 3783 Thatcher, W. W., M. D. Meyer, and G. Danet-Desnoyers. (1995). Maternal Recognition of
3784 Pregnancy. *Journal of Reproduction and Fertility* **49**, 15–28.

- 3785 Thompson, M. B., J. R. Stewart, and B. K. Speake. (2000). Comparison of Nutrient Transport
3786 across the Placenta of Lizards Differing in Placental Complexity. *Comparative*
3787 *Biochemistry and Physiology - A Molecular and Integrative Physiology* **127**(4), 469–79.
- 3788 Thompson, M. B., J. R. Stewart, B. K. Speake, K. J. Russell, and R. J. McCartney. (1999).
3789 Placental Transfer of Nutrients during Gestation in the Viviparous Lizard, *Pseudemoia*
3790 *spenceri*. *Journal of Comparative Physiology - B Biochemical, Systemic, and*
3791 *Environmental Physiology* **169**(4–5), 319–28.
- 3792 Thompson, M. B., L. A. Lindsay, J. F. Herbert, and C. R. Murphy. (2007). Calcium ATPase
3793 Expression in the Oviducts of the Skink, *Lampropholis guichenoti*. *Comparative*
3794 *Biochemistry and Physiology - A Molecular and Integrative Physiology* **147**(4), 1090–94.
- 3795 Thompson, M. B., and B. K. Speake. (2002). Energy and Nutrient Utilization by Embryonic
3796 Reptiles. *Comparative Biochemistry and Physiology - A Molecular and Integrative*
3797 *Physiology* **133**(3), 529–38.
- 3798 ———. (2003). Energy and nutrient utilisation by embryonic reptiles. *Comparative*
3799 *Biochemistry and Physiology - A Molecular and Integrative Physiology* **133**, 529–538.
- 3800 ———. (2006). A Review of the Evolution of Viviparity in Lizards: Structure, Function and
3801 Physiology of the Placenta. *Journal of Comparative Physiology B: Biochemical, Systemic,*
3802 *and Environmental Physiology* **176**(3), 179–89.
- 3803 Tian, X., J. Gautron, P. Monget, and G. Pascal. (2010). What Makes an Egg Unique? Clues from
3804 Evolutionary Scenarios of Egg-Specific Genes. *Biology of Reproduction* **83**(6), 893–900.

3805 Ticconi, C., A. Zicari, A. Belmonte, M. Realacci, C. V. Rao, and E. Piccione. (2007). Pregnancy-
3806 Promoting Actions of HCG in Human Myometrium and Fetal Membranes. *Placenta* **28**,
3807 S137–43.

3808 Tilburgs, T., S. A. Scherjon, and F. H.J. Claas. (2010). Major Histocompatibility Complex
3809 (MHC)-Mediated Immune Regulation of Decidual Leukocytes at the Fetal-Maternal
3810 Interface. *Journal of Reproductive Immunology* **85**(1): 58–62.

3811 Tinkle, D. W., and J. Whitfield Gibbons. (1977). The Distribution and Evolution of Viviparity in
3812 Reptiles. *Miscellaneous Publications Museum of Zoology University of Michigan* **154**,1–55.

3813 Torricelli, M., A. Giovannelli, E. Leucci, G. De Falco, F. M. Reis, A. Imperatore, P. Florio, and
3814 F. Petraglia. (2007). Labor (Term and Preterm) Is Associated with Changes in the Placental
3815 mRNA Expression of Corticotrophin-Releasing Factor. *Reproductive Sciences* **14**(3), 241–
3816 45.

3817 Torry, D. S., D. Mukherjea, J. Arroyo, and R. J. Torry. (2003). Expression and Function of
3818 Placenta Growth Factor: Implications for Abnormal Placentation. *Journal of the Society for*
3819 *Gynecologic Investigation* **10**(4), 178–88.

3820 Trauth, S. E., and W. R. Fagerberg. (1984). Ultrastructure and Stereology of the Eggshell in
3821 *Cnemidophorus sexlineatus* (Lacertilia: Teiidae). *Copeia* **1984**(4), 826.

3822 Trowsdale, J. (2011). The MHC, Disease and Selection. *Immunology Letters* **137**(1–2), 1–8.

3823 Trowsdale, J., and A. G. Betz. (2006). Mother’s Little Helpers: Mechanisms of Maternal-Fetal
3824 Tolerance. *Nature Immunology* **7**(3), 241–46.

- 3825 Truong, A. D., Y. Hong, J. Lee, K. Lee, D. Y. Kil, H. S. Lillehoj, and Y. H. Hong. (2018).
3826 Interleukin-34 Regulates Th1 and Th17 Cytokine Production by Activating Multiple
3827 Signaling Pathways through CSF-1R in Chicken Cell Lines. *International Journal of*
3828 *Molecular Sciences* **19**(6), 1–19.
- 3829 Tuan, R., and T. Ono. (1986). Regulation of Extraembryonic Calcium Mobilization by the
3830 Developing Chick Embryo. *Journal of Embryology and Experimental Morphology* **97**, 63–
3831 74.
- 3832 Tuan, R. S., M. J. Carson, J. A. Jozefiak, K. A. Knowles, and B. A. Shotwell. (1986). Calcium-
3833 Transport Function of the Chick Embryonic Chorioallantoic Membrane. I. In Vivo and in
3834 Vitro Characterization. *Journal of Cell Science* **82**, 73–84.
- 3835 Tuan, R. S., and K. A. Knowles. (1984). Calcium-Activated ATPase of the Chick Embryonic
3836 Chorioallantoic Membrane. Identification, Developmental Expression, and Topographic
3837 Relationship with Calcium-Binding Protein. *Journal of Biological Chemistry* **259**(5), 2754–
3838 63.
- 3839 Tuan, R. S., and W. A. Scott. (1977). Calcium Binding Protein of Chorioallantoic Membrane:
3840 Identification and Developmental Expression. *Proceedings of the National Academy of*
3841 *Sciences* **74**(5), 1946–49.
- 3842 Tuan, R. S., W. A. Scott, and Z. A. Cohn. (1978). Calcium-Binding Chorioallantoic Protein of the
3843 Chick Membrane I. Immunohistochemical Localization Enzymatic Dissociation of CAM
3844 into Single Cells Purification of the CaBP. *Journal of Cellular Biology* **77**(3), 743-51.

- 3845 Turin, L., P. Invernizzi, M. Woodcock, F. R. Grati, F. Riva, G. Tribbioli, and G. Laible. (2007).
3846 Bovine Fetal Microchimerism in Normal and Embryo Transfer Pregnancies and Its
3847 Implications for Biotechnology Applications in Cattle. *Biotechnology Journal* **2**(4), 486–91.
- 3848 Tyler, C. (1965). A Study of the Egg Shells of the Sphenisciformes. *Proceedings of the*
3849 *Zoological Society of London* **147**, 1–19.
- 3850 Ugurel, S., V. Rebmann, S. Ferrone, W. Tilgen, H. Grosse-Wilde, and U. Reinhold. (2001).
3851 Soluble Human Leukocyte Antigen–G Serum Level Is Elevated in Melanoma Patients and
3852 Is Further Increased by Interferon- α Immunotherapy. *Cancer: Interdisciplinary*
3853 *International Journal of the American Cancer Society* **92**(2), 369–76.
- 3854 Uller, T., C. Isaksson, and M. Olsson. (2006). Immune Challenge Reduces Reproductive Output
3855 and Growth in a Lizard. *Functional Ecology* **20**(5), 873–79.
- 3856 Uribe, C., H. Folch, R. Enriquez, and G. Moran. (2011). Innate and Adaptive Immunity in
3857 Teleost Fish: A Review. *Veterinarni Medicina* **56**(10), 486–503.
- 3858 Van Dyke, J. U., M. C. Brandley, and M. B. Thompson. (2014). The Evolution of Viviparity:
3859 Molecular and Genomic Data from Squamate Reptiles Advance Understanding of Live
3860 Birth in Amniotes. *Reproduction* **147**(1).
- 3861 Vannuccini, S., C. Bocchi, F. M. Severi, J. R. Challis, and F. Petraglia. (2016). Endocrinology of
3862 Human Parturition. *Annales d'Endocrinologie* **77**(2), 105–13.

- 3863 Vieira, S., G. De Perez, and M. Patricia Ramírez-Pinilla. (2007). Invasive Cells in the
3864 Placentome of Andean Populations of *Mabuya*: An Endotheliochorial Contribution to the
3865 Placenta? *Anatomical Record* **290**(12), 1508–18.
- 3866 Visser, J. (1975). Oviparity in Two South African Skinks of the Genus *Mabuya*, with Notes on
3867 Hatching. *Zoologica Africana* **10**(2), 209–13.
- 3868 Vogel, P. (2005). The Current Molecular Phylogeny of Eutherian Mammals Challenges Previous
3869 Interpretations of Placental Evolution. *Placenta* **26**(8–9), 591–96.
- 3870 Vokes, S. A., and P. A. Krieg. (2002). Endoderm Is Required for Vascular Endothelial Tube
3871 Formation, but Not for Angioblast Specification. *Development* **129**(3), 775–85.
- 3872 Vonnahme, K. A., M. E. Wilson, and S. P. Ford. (2002). Conceptus Competition for Uterine
3873 Space: Different Strategies Exhibited by the Meishan and Yorkshire Pig. *Journal of Animal*
3874 *Science* **80**(5), 1311–16.
- 3875 Vonnahme, K. A., M. E. Wilson, and S. P. Ford. (2001). Relationship between Placental
3876 Vascular Endothelial Growth Factor Expression and Placental/Endometrial Vascularity in
3877 the Pig. *Biology of Reproduction* **64**(6), 1821–25.
- 3878 Wagner, G. P., K. Kin, L. Muglia, and M. Pavličev. (2014). Evolution of Mammalian Pregnancy
3879 and the Origin of the Decidual Stromal Cell. *International Journal of Developmental*
3880 *Biology* **58**(2–4), 117–26.

3881 Wasserman, R. H., C. A. Smith, C. M. Smith, M. E. Brindak, C. S. Fullmer, L. Krook, J. T.
3882 Penniston, and R. Kumar. (1991). Immunohistochemical Localization of a Calcium Pump
3883 and Calbindin-D28k in the Oviduct of the Laying Hen. *Histochemistry* **96**(5), 413–18.

3884 Weiss, G., and L. T. Goldsmith. (2001). Relaxin and the Cervix. *The Endocrinology of*
3885 *Parturition* **27**, 105–12.

3886 Wen, Y., W. Fang, L. X. Xiang, R. L. Pan, and J. Z. Shao. (2011). Identification of Treg-like
3887 Cells in Tetraodon: Insight into the Origin of Regulatory T Subsets during Early Vertebrate
3888 Evolution. *Cellular and Molecular Life Sciences* **68**(15), 2615–26.

3889 Whittington, C. M., K. Danastas, G. E. Grau, C. R. Murphy, and M. B. Thompson. (2017).
3890 Expression of VEGF111 and Other VEGF-A Variants in the Rat Uterus Is Correlated with
3891 Stage of Pregnancy. *Journal of Comparative Physiology B: Biochemical, Systemic, and*
3892 *Environmental Physiology* **187**(2), 353–60.

3893 Whittington, C. M., G. E. Grau, C. R. Murphy, and M. B. Thompson. (2015). Unusual
3894 Angiogenic Factor Plays a Role in Lizard Pregnancy but Is Not Unique to Viviparity.
3895 *Journal of Experimental Zoology Part B: Molecular and Developmental Evolution* **324**(2),
3896 152–58.

3897 Whittington, C. M., D. O’Meally, M. K. Laird, K. Belov, M. B. Thompson, and B. M. McAllan.
3898 (2018). Transcriptomic Changes in the Pre-Implantation Uterus Highlight Histotrophic
3899 Nutrition of the Developing Marsupial Embryo. *Scientific Reports* **8**(1), 1–18.

3900 Whittington, C. M., J. U. Van Dyke, S. Q. T. Liang, S. V. Edwards, R. Shine, M. B. Thompson,
3901 C. E. Grueber. (2022) Understanding the evolution of viviparity using intraspecific variation

3902 in reproductive mode and transitional forms of pregnancy. *Biological Reviews* **97**(3), 1179-
3903 1192

3904 Whittle, W. L., A. C. Holloway, S. J. Lye, W. Gibb, and J. R. G. Challis. (2000). Prostaglandin
3905 Production at the Onset of Ovine Parturition Is Regulated by Both Estrogen-Independent
3906 and Estrogen-Dependent Pathways. *Endocrinology* **141**(10), 3783–91.

3907 Wienke, J., L. Brouwers, L. van der Burg, M. Mokry, R. C. Scholman, P. G. J. Nikkels, B. van
3908 Rijn, and F. van Wijk. (2020). Human Tregs at the materno-fetal interface show site-
3909 specific adaptation reminiscent of tumor Tregs. *Journal of Clinical Investigation Insight*
3910 **5**(18), e137926.

3911 Williams, T. D. (2012). *Physiological Adaptations for Breeding in Birds*. Princeton and Oxford:
3912 Princeton University Press.

3913 Wilt, F. H. (1965). Erythropoiesis in the Chick Embryo: The Role of Endoderm. *Science* **147**,
3914 1588–90.

3915 Withanage, G. S. K., K. Sasai, T. Fukata, T. Miyamoto, H. S. Lillehoj, and E. Baba. (2003).
3916 Increased Lymphocyte Subpopulations and Macrophages in the Ovaries and Oviducts of
3917 Laying Hens Infected with Salmonella Enterica Serovar Enteritidis. *Avian Pathology* **32**(6),
3918 583–90.

3919 Wooding, F. B. P., M. P. Ramirez-Pinilla, and A. S. Forhead. (2010). Functional Studies of the
3920 Placenta of the Lizard *Mabuya sp.* (Scincidae) Using Immunocytochemistry. *Placenta*
3921 **31**(8), 675–85.

- 3922 Wootton, R., I. R. McFadyen, and J. E. Cooper. (1977). Measurement of Placental Blood Flow in
3923 the Pig and Its Relation to Placental and Fetal Weight. *Neonatology* **31**(5–6), 333–39.
- 3924 Work, T. M., G. H. Balazs, R. A. Rameyer, S. P. Chang, and J. Berestecky. (2000). Assessing
3925 Humoral and Cell-Mediated Immune Response in Hawaiian Green Turtles, *Chelonia*
3926 *mydas*. *Veterinary Immunology and Immunopathology* **74**(3–4), 179–94.
- 3927 Wray, S., T. Burdyga, D. Noble, K. Noble, L. Borysova, and S. Arrowsmith. (2015). Progress in
3928 Understanding Electro-Mechanical Signalling in the Myometrium. *Acta Physiologica*
3929 **213**(2), 417–31.
- 3930 Wu, C., C. Lv, Y. Wan, X. Li, J. Zhang, J. Li, and Y. Wang. (2019). Arginine Vasotocin
3931 (AVT)/Mesotocin (MT) Receptors in Chickens: Evidence for the Possible Involvement of
3932 AVT-AVPR1 Signaling in the Regulation of Oviposition and Pituitary Prolactin
3933 Expression. *General and Comparative Endocrinology* **281**(Jan), 91–104.
- 3934 Wu, L., L. H. Luo, Y. X. Zhang, Q. Li, B. Xu, G. X. Zhou, H. B. Luan, and Y. S. Liu. (2014).
3935 Alteration of Th17 and Treg Cells in Patients with Unexplained Recurrent Spontaneous
3936 Abortion before and after Lymphocyte Immunization Therapy. *Reproductive Biology and*
3937 *Endocrinology* **12**(1), 1–9.
- 3938 Wu, Q., M. B. Thompson, and C. R. Murphy. (2011). Changing Distribution of Cadherins during
3939 Gestation in the Uterine Epithelium of Lizards. *Journal of Experimental Zoology Part B:*
3940 *Molecular and Developmental Evolution* **316**(6), 440–50.

- 3941 **Xie, H.-X., X.X Liang, W.M. Li, Z.Q. Chen, X.F. Wang, Z.H. Ding, X.M. Zhou, and W.G**
3942 **Du.** (2022). The eggshell-matrix protein gene OC-17 is functionally lost in the viviparous
3943 Chinese crocodile lizard. *Journal of Evolutionary Biology* **35**, 1568–1575.
- 3944 Yagel, S., P. K. Lala, W. A. Powell, and R. F. Casper. (1989). Interleukin-1 Stimulates Human
3945 Chorionic Gonadotropin Secretion by First Trimester Human Trophoblast. *The Journal of*
3946 *Clinical Endocrinology & Metabolism* **68**(5), 992–95.
- 3947 Yang, F., Q. Zheng, and L. Jin. (2019). Dynamic Function and Composition Changes of Immune
3948 Cells During Normal and Pathological Pregnancy at the Maternal-Fetal Interface. *Frontiers*
3949 *in Immunology* **10**, 1–15.
- 3950 Yang, J. H., Z. H. Zhao, J. F. Hou, Z. L. Zhou, Y. F. Deng, and J. J. Dai. (2013). Expression of
3951 TRPV6 and CaBP-D28k in the Egg Shell Gland (Uterus) during the Oviposition Cycle of
3952 the Laying Hen. *British Poultry Science* **54**(3), 398–406.
- 3953 Yang, X., F. Zhao, Q. Han, Y. Dong, J. Lei, C. Yang, Y. Guo, K. Ito, and B. Zhang. (2020).
3954 Transcriptome Analysis in the Shell Gland of Laying Hens Affecting Eggshell Qualities.
3955 *Research Square* 1–19.
- 3956 Yang, Y., D. E. Geraghty, and J. S. Hunt. (1995). Cytokine Regulation of HLA-G Expression in
3957 Human Trophoblast Cell Lines. *Journal of Reproductive Immunology* **29**(3), 179–95.
- 3958 Yie, S. M., L. H. Li, G. M. Li, R. Xiao, and C. L. Librach. (2006). Progesterone Enhances HLA-
3959 G Gene Expression in JEG-3 Choriocarcinoma Cells and Human Cytotrophoblasts in Vitro.
3960 *Human Reproduction* **21**(1), 46–51.

- 3961 Yie, S. M., R. Xiao, and C. L. Librach. (2006). Progesterone Regulates HLA-G Gene Expression
3962 through a Novel Progesterone Response Element. *Human Reproduction* **21**(10), 2538–44.
- 3963 Yoshimura, Y., T. Okamoto, and T. Tamura. (1997). Localisation of MHC Class II,
3964 Lymphocytes and Immunoglobulins in the Oviduct of Laying and Moulting Hens. *British*
3965 *Poultry Science* **38**(5), 590–96.
- 3966 Yoshinaga, K. (2008). Review of Factors Essential for Blastocyst Implantation for Their
3967 Modulating Effects on the Maternal Immune System. In *Seminars in Cell & Developmental*
3968 *Biology* **19**, 161–69.
- 3969 Yoshizawa, R. S. (2016). Fetal–Maternal Intra-Action: Politics of New Placental Biologies. *Body*
3970 *and Society* **22**(4), 79–105.
- 3971 Young, I. R., M. B. Renfree, S. Mesiano, G. Shaw, G. Jenkin, and R. Smith. (2011). The
3972 Comparative Physiology of Parturition in Mammals: Hormones and Parturition in
3973 Mammals. *Hormones and Reproduction of Vertebrates* **5**.
- 3974 **Yurchenko A.A, H. Recknagel, and K.R Elmer. (2020)** Chromosome-Level Assembly of the
3975 Common Lizard (*Zootoca vivipara*) Genome. *Genome Biology and Evolution* **12**(11), 1953-
3976 1960
- 3977 Zenclussen, M. L., C. Thuere, N. Ahmad, P. O. Wafula, S. Fest, A. Teles, A. Leber, et al. (2010).
3978 The Persistence of Paternal Antigens in the Maternal Body Is Involved in Regulatory T-Cell
3979 Expansion and Fetal-Maternal Tolerance in Murine Pregnancy. *American Journal of*
3980 *Reproductive Immunology* **63**(3), 200–208.

3981 Zettergren, L. D., and R. T. Cutlan. (1992). Immunoglobulin-containing Cells in Chick Embryo
3982 Urogenital Tissues: A New Site for Early B Lineage Cells in Endothermic Vertebrates.
3983 *Journal of Experimental Zoology* **262**(4), 458–61.

3984 Zhang, J., Y. Wang, C. Zhang, M. Xiong, S. A. Rajput, Y. Liu, and D. Qi. (2019). The
3985 Differences of Gonadal Hormones and Uterine Transcriptome during Shell Calcification of
3986 Hens Laying Hard or Weak-Shelled Eggs. *BMC Genomics* **20**(1), 1–12.

3987 Zimmerman, L. M., L. A. Vogel, and R. M. Bowden. (2010). Commentary: Understanding the
3988 Vertebrate Immune System: Insights from the Reptilian Perspective. *Journal of*
3989 *Experimental Biology* **213**(5), 661–71.

3990 Zimmerman, L. M. (2020). The Reptilian Perspective on Vertebrate Immunity: 10 Years of
3991 Progress. *The Journal of Experimental Biology* **223**.

3992 Zimmerman, L. M., R. M. Bowden, and L. A. Vogel. (2014). A Vertebrate Cytokine Primer for
3993 Eco-Immunologists. *Functional Ecology* **28**(5), 1061–73.

3994 **Zimin, A., Zimin, S. V., Shine, R., Avila, L., Bauer, A., Böhm, M., Brown, R., Barki, G., de**
3995 **Oliveira Caetano, G. H., Castro Herrera, F., Chapple, D. G., Chirio, L., Colli, G. R., Doan,**
3996 **T. M., Glaw, F., Grismer, L. L., Itescu, Y., Kraus, F., LeBreton, M. et al., (2022). A global**
3997 **analysis of viviparity in squamates highlights its prevalence in cold climates. *Global***
3998 ***Ecology and Biogeography* **31**(12), 2437–2452.**

3999 Zoccola, D., A. Moya, G. E. Béranger, E. Tambutté, D. Allemand, G. F. Carle, and S. Tambutté.
4000 (2009). Specific Expression of BMP2/4 Ortholog in Biomineralizing Tissues of Corals and
4001 Action on Mouse BMP Receptor. *Marine Biotechnology* **11**(2), 260–69.