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The Ostrich (*Struthio camelus*) Egg – a Safety Seat in the Time Vehicle

Ross G. COOPER[1,*], Marek ŁUKASZEWICZ[2], Jaroslaw O. HORBAŃCZUK[2]

[1]Division of Physiology, Birmingham City University, 704 Baker Building, Franchise Street, Birmingham B42 2SU, UK.

[2]Department of Animal Sciences, Institute of Genetics and Animal Breeding, Polish Academy of Sciences, Jastrzębiec, Postępu 1, 05-552 Wólka, Kosowska, POLAND

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Abstract: The role of the egg is 2-fold – protection of the contents and conditioning the incubation. We used a variety of search engines to collate literature pertinent to the ostrich egg from PubMed, Medline, and Agricola. An ostrich egg weighs ca. 1.5 kg, and the mean length and width are 156 and 129 mm, respectively. The vertical and horizontal circumferences reach a maximum of 45 and 40 cm, respectively. Average internal volume is ca. 1350 ml. The mean weight of albumen in a 1500 g ostrich egg reaches 900 g, with a 317 g yolk and a 296 g voided shell. The shell thickness ranges from 1.6 to 2.2 mm. Instron-determination of the eggshell strength reached some 70 kg (~686 N), while that of chicken eggshells was 3-4 kg. Thus, an ostrich egg can potentially withstand the weight of an adult human being. The egg that possesses the best genetic manifestations of size and shape is likely to be located in the centre of a nest, thus providing optimal incubating conditions.

Key Words: Egg, evolution, ostrich

The egg's role was regarded as supporting the lineage of a species and of the features, which were presumably continuously developed and improved along the evolution course. The role of the egg is 2-fold – protection of the contents and conditioning the incubation. Obvious egg endogenic features are shape, shell, and structure, together resulting in strength and colour. Exogenic features protect the egg and stipulate the incubation process. Emulated in the latter are characteristic behaviours of the dominant hen including placing her eggs in the centre of the nest (1), the colouration of plumage (2), size and strength of the birds, adaptability of the species to different environments (food, climate), and the chick's adaptability to hatch. In fact, all the preceding defines the protected "content" of an egg – it is the sampled gene collection transferred to subsequent generations. In this paper we collated a series of papers pertinent to the ostrich and sought to accumulate detail on the anatomical characteristics of the egg and make some comparisons with other egg-layers. We hoped the material therein would be useful for avian veterinarians.

We used a variety of search engines to collate literature pertinent to the ostrich egg from PubMed, Medline, and Agricola. The criteria used to select articles to be included were both theoretically and practically motivated and adopted from proposed criteria listed below:

- Positive selection of literature was determined by appropriateness of methodology, adequacy of subject numbers, specificity of sex and/or age of birds, and statistically significant response rates.

* E-mail: rgcooperuk@yahoo.com

- The time frame used was 1900-2008, inclusive.
- A multi-factorial overview was performed and the critical and relevant factors of evolution, egg characteristics, nutrition and feeding of the ostrich hen were selected and incorporated into the current paper.
- Compilation of materials began with published literature or easily accessible academic research.
- The research strategy was refined using particular search terms, including egg, evolution, nutrition, feeding, and ostrich.

We also utilised a device (Instron, 4301, Instron Corporation, Conton, Massachusetts, USA) (Figure 1) to record the applied force (range up to a maximum of 5 kN) at crack (cylinder bolt compressing the arch of the oval along the longer axis of the egg at a speed of 20 mm min^{-1}).

The paleontological evidence indicates that birds inherited the shape and the structure of the eggshell from their egg-laying predecessors (3). Likewise, the basics of the exogenic egg features, for example, nesting behaviour (4), could have been acquired from the non-avian ancestors. Birds evolved over 150-200 million years ago (mya) during the Mesozoic era from the Pterosaurs, or flying dinosaurs. This period may have been variable, as 2 new species of feathered dinosaurs were discovered in China dating 125-145 mya. An Archaeopteryx fossil found in 1861 in Germany revealed the first clue of the ancestral link between reptiles and birds. Archaeopteryx evolved ca. 144 (Early Cretaceous) -163 (Late Jurassic) mya. Another discovery, Liaoningornis, lived 135 mya and possessed a breastbone similar to that of modern birds, with massive flight muscles that enabled sustained flight. It was discovered alongside fossils of ancient birds not unlike Archaeopteryx. It is thought that birds were very widespread by that date, occupying a variety of habitats. Most of them, however, died out with the dinosaurs, about 65 mya. Feduccia (5) stated that the ancestors of all of today's birds evolved later, between 53 and 65 mya (Palaeocene), independently of the dinosaurs. Sibley and Ahlquist (6) added that the opening of the Atlantic ca. 80 mya caused the divergence between the lineages that produced the living ostrich and rheas. The shape and shell structure of the avian egg had been well developed by that time.

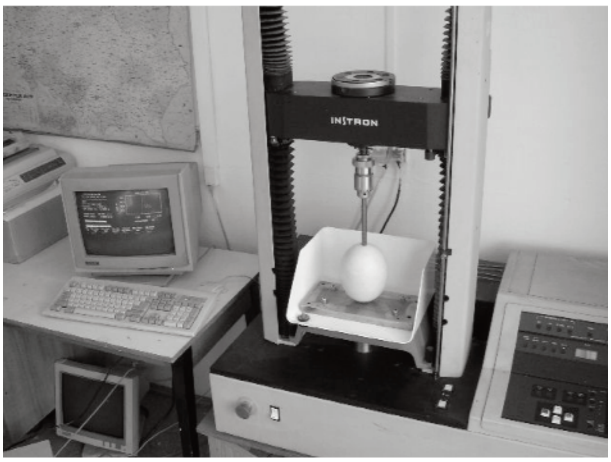

Figure 1. Use of an Instron to determine vertical shear force required to fracture the ostrich eggshell.

The ostrich (Aves, Palaeognathae, Struthioniformes) is a member of the Ratitae, fossil evidence of which suggests that they evolved from Cursorial birds of medium size that inhabited the Asian steppes 40-55 mya (7). Although the global population size of ostriches has not been quantified, it is thought to be large, as the species is identified in numerous parts of its range (7). Fortunately, the species is not believed to be approaching thresholds of population decline of more than 30% over 10 years or 3 generations. According to a rough estimation, the world ostrich population is around 2 million birds, approximately one-third living in Africa (8). Over 90% of the ostrich population in Africa is kept on farms or in zoological gardens, whilst the remainder lives in the wild (8). Indeed, it is testimony of the significant adaptability of this species.

An ostrich egg weighs ca. 1.5 kg, and the mean length and width are 156 and 129 mm, respectively. The vertical and horizontal circumferences reach a maximum of 45 and 40 cm, respectively (9,10). Average internal volume is ca. 1350 ml. The mean weight of albumen in a 1500 g ostrich egg reaches 900 g, with a 317 g yolk and a 296 g voided shell. The shell thickness ranges from 1.6 to 2.2 mm (11).

The egg shape seems to be a compromise between the ease of laying (oval dimension) and the management of mineral resources (spherical dimension). The spherical shape ensures the most economical shape to encompass a given volume, i.e. less calcium is required during egg formation. The shape of an egg can be described with its index being the percentage ratio of width to length: from spherical (close to 100) to a whole spectrum of oval shapes (100>). Ostrich egg index has been found to range between 76 and 86. The egg is more spherical (84-85) during the first year of laying, attenuating to 81-82, with age (11). The same tendency has also been reported in the chicken (12) although at index values right below those for ostrich. Since the strength of the eggshell is, amongst others, a function of the index (13) (spherical eggs are stronger), the ostrich egg possesses additional strength due to its shape, relative to the chicken. Egg shape may also vary slightly depending on the hen's nutrition and the calcium content of the shell (10).

The point-wise pressure an ostrich egg can withstand has been estimated very widely: from 47 to 120 kg (7,14). Nonetheless, it is difficult to crush an ostrich egg, given its eggshell strength and positioning in the sand, which ensures that it is not damaged by an incubating parent. Instron-determination of the eggshell strength reached some 70 kg (~686 N), while that of chicken eggshells was 3-4 kg. Thus, an ostrich egg can potentially withstand the weight of an adult human being.

The great absolute strength of the ostrich egg, an endogenic feature, has usually been associated with the necessity of protecting it against predators. Minor predators, for example, the jackal, feed on ostrich eggs only occasionally; indeed, they fear the guarding ostrich parents. On the other hand, a 70 kg breaking force of an ostrich egg for a major predator (e.g. the hyena) is not an obstacle.

The white colouration of ostrich eggs defies the notion that white eggs are least likely to occur in families that nest on the ground (15). Since, however, most wandering animals will stay clear due to fierce parental guarding the white colour of the eggs may play a thermoregulation role. The light colour of the ostrich egg allows it to reflect 98% of the red and near infrared light from the sun (16). In the natural environment it is a great advantage, particularly when the eggs are left in an open nest and exposed to the sun, which heats the top surface of the egg to around 45 °C at midday, whilst the centre of the egg reaches over 40 °C during the late afternoon (16). Alteration of the natural creamy white colour to brown by applying crayons exerted a lethal effect (17).

Species that lay eggs but do not incubate them, for example, crocodiles or turtles, rely principally on the humidity and temperature of the surroundings, although commonly they adapt these requirements, for instance, via the use of a nest of rotting leaves or laying directly into a sand burrow, respectively. Their eggs are covered with, at most, a thin shell and some of them are leathery soft. We conclude, therefore, that their eggs do not need strong shells because the parents do not endanger them. An allied example is the cuckoo, whose egg may be exposed to deliberate destruction when recognised by a host as alien; thus a strong shell is a prerequisite (18). A soft shell can be found in egg-incubating species of Monotremata. However, in the platypus, the egg develops in utero for ca. 28 days with ca. 10 days of external incubation (19); in contrast, the ostrich egg is enclosed for ca. 2 days in the oviduct and incubated for ca. 42 days externally. Following egg laying the female platypus curls around the eggs and incubates against her abdomen (by clasping them with her tail). In other words, the eggs are handled in a similar way to the pups.

The avian eggshell may endow strength in the ostrich egg to survive in tough climatic conditions, particularly desert environments. Indeed, natural selection ensures the maintenance of this strength within ranges enabling hatching. There is, however, another evolutionary aspect of this development. The coupling of a dominant hen and

Figure 2. Remarkable comparison of the extinct elephant bird (*Aepyornis* spp.) egg with an ostrich (*Struthio camelus*) egg (Courtesy of Dr. C. Madeiros).

cock produces, presumably, the best genetic combination that is selected in the "time vehicle". The eggs possessing the best genetic manifestations of size and shape are likely to be located in the centre of a nest, thus providing optimal incubating conditions; a distracted parent or an opportunistic predator will least jeopardise them. The surrounding, more vulnerable eggs serve simply as additional lateral protection for the centrally located eggs.

Concluding, we would like to postulate the problem of "why the ostrich egg is so fragile" rather than "why it is so strong"! Indeed, we need to relate the egg size and strength to the body weight of the parent. Our answer is that the outstanding exogenic features ensure that the egg is tough and diminishes the necessity of the eggshell to develop strength to sustain an incubating parent's body weight and survive in a harsh environment like a desert; this makes it easier for the chicks to hatch. Certainly, this is direct evolution occurring on-site. We have not found, however, answers to a few important questions that would help us conclude this proposition more definitely. For instance, what is the hatching rate from the centrally placed eggs compared with that of the peripheral ones? Is the position of an alpha parent hen/cock inherited? What is the actual proportion of eggs damaged by the parents? What are the age profiles of the ostrich social groups? Are the peripheral eggs in a nest stronger because of the presence of younger companion hens? Do the ostrich eggs weaken as the hen ages? Surely these questions ought to be answered before we can thoroughly deduce the miraculous features of the ostrich egg. Additionally work needs to be extended to compare ostrich egg shell characteristics with those of other bird species (20) to predict evolutionary divergence, including extinct ratites (Figure 2).

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