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APPENDIX

Derivation of the probability of inclusion.—Let P(S) represent the probability of the event S, let E represent exclusion from the sample, and let t represent the randomly selected time unit on which the first search will be conducted. Then

$$\begin{aligned}\pi(x) &= 1 - P(E)\\ &= 1 - \sum_t P(E \cap t)\\ &= 1 - \sum_t P(E \mid t)P(t)\\ &= 1 - \frac{1}{d}\sum_t P(E \mid t), \end{aligned} \quad (11)$$

since $P(t) = 1/d$. Now, $d(\theta + 1) - x$ choices of t result in θ searches being conducted during the x time units a nest is in existence and $x - d\theta$ choices of t result in $\theta + 1$ searches being conducted. As the searches are assumed independent and the probability of detecting a nest on any one search is β if it is in existence and 0 if it is not,

$$\pi(x) = 1 - \frac{1}{d}[(d(\theta + 1) - x)(1 - \beta)^{\theta} + (x - d\theta)(1 - \beta)^{\theta+1}]. \quad (12)$$

This function can easily be written in the form given in equation (1).

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Application of Computed Tomography to Morphological Study of Emperor and Adélie Penguins

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Computed tomography (CT) has been commonly applied to medical science and clinics. This scanning technique also has been applied to the functional physiology of human muscle. Häggmark et al. (1978), Schantz et al. (1983) and Borkan et al. (1983) used CT for measuring the cross-sectional area of muscle and subcutaneous fat. Through these studies it was revealed that CT provides a rapid and accurate measuring method without sectioning of material.

Using CT, we first attempted to measure the body and organ cross-sectional area of one male Emperor Penguin (*Aptenodytes forsteri;* the largest penguin) and one female Adélie Penguin (*Pygoscelis adeliae;* a medium-sized penguin), which were initially collected for measuring heavy-metal concentrations. We calculated the body and organ volumes from the serial measurements of cross-sectional area as part of a morphological analysis of internal organ size. Here we report the preliminary results of our study.

Methods.—We collected the Emperor and Adélie penguins from Riiser-Larsen Peninsula (68°50′S, 34°40′E) and Langhovde (69°13′S, 39°39′W), Antarctica on 19 September 1990 and 18 January 1991, respectively. The birds were euthanized by intermuscular injection of Ketamine hydrochloride and kept frozen at −20°C. The frozen materials were laterally scanned by a Yokogawa CT scanner (ImageMax II). CT images were obtained at 10-mm intervals, perpendicular to the longitudinal body axis from top of the beak to end of the foot extended caudad. Images were filmed

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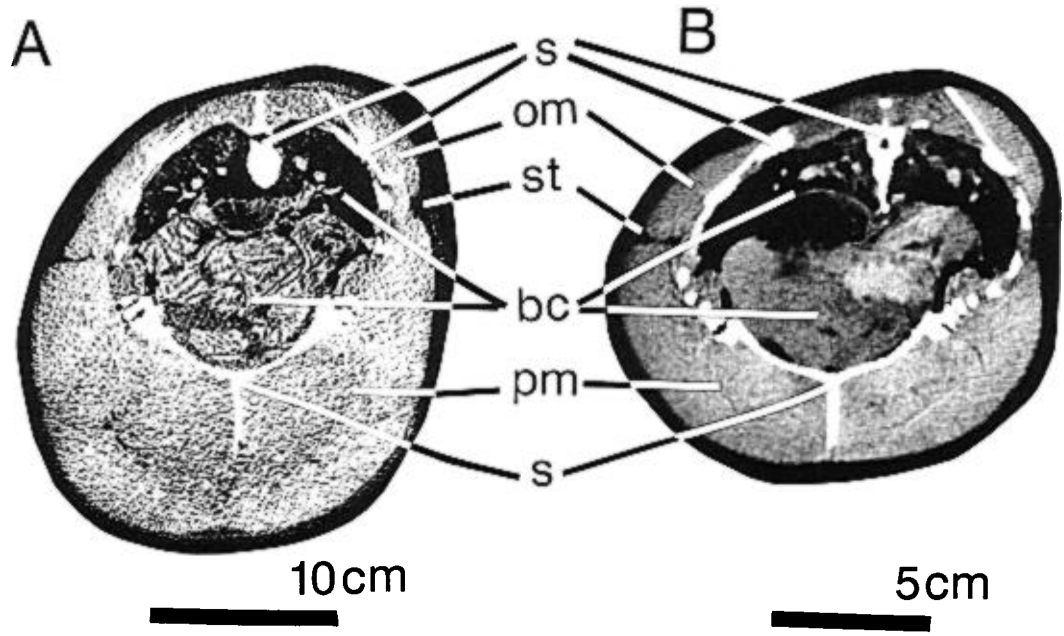

Fig. 1. Cross-sectional images of thorax: (A) Emperor Penguin; and (B) Adélie Penguin. Abbreviations: (st) subcutaneous tissue; (pm) pectoral muscle; (om) other muscle; (bc) body cavity; (s) skeleton.

using a Yokogawa Multi-format camera. Software of the CT scanner was used to calculate CT attenuation number (i.e. index of tissue density relative to density of water) based on the brightness of picture elements. In order to obtain a clear outline of tissues, we selected the narrow range of the picture elements (−125 to 125 Hounsfield units [HU]; maximum range −1,000 to 2,000 HU) for the CT attenuation number. We chose CT attenuation number to be less than −100 HU for fat, and greater than 125 HU for skeleton, according to Borkan et al. (1982); the values of other organ categories range between these two values. We classified a body cross section into five organ categories: subcutaneous tissue (mainly fat); pectoral muscle; other muscle (muscle system except the pectoral muscle); body cavity (digestive, respiratory, circulatory, and genital systems); and skeleton (skeleton and some horny structures [beak and nail]).

The cross-sectional area was measured by transferring the outlines of the body and organs to tracing paper, and cutting out and weighing scraps of respective paper on which organ categories were outlined; the relationship between the paper weight and area had previously been determined (Schantz et al. 1981). The approximate volumes (V; cm^3) of the body and organ categories were calculated by the equation

$$V = Li \times \Sigma Ac, \quad (1)$$

where Li is the length of interval between images (in this case, 1 cm) and Ac (cm^2) is cross-sectional area of the total body or organ categories in each image, of which we took 100 and 65 for Emperor and Adélie penguins, respectively. Wing volume was not included when we determined body volume.

CT images of the thoraxes of Emperor and Adélie penguins are shown in Figure 1. There was an obvious

TABLE 1. Body size and organ volumes of single specimens of Emperor and Adélie penguins. Percent of each organ to total body volume shown in parentheses.

Variable	Emperor Penguin	Adélie Penguin
Body mass (kg)	24.0	4.6
Body volume (cm^3)	22,910	4,260
Skeleton volume (cm^3)	1,790 (7.81)	430 (10.09)
Pectoral muscle volume (cm^3)	6,800 (29.68)	750 (17.61)
Other muscle volume (cm^3)	5,160 (22.52)	980 (23.00)
Body cavity volume (cm^3)	5,610 (24.49)	1,840 (43.19)
Subcutaneous tissue volume (cm^3)	3,540 (15.45)	240 (5.63)

difference in the body composition between the Emperor and Adélie penguins (Fig. 1 and Table 1). The pectoral muscle of the Emperor Penguin, in proportion to the body volume, was much larger than that of the Adélie Penguin (29.68 and 17.61%, respectively), while the other muscles were similar (22.52 and 23.00%, respectively). The larger pectoral muscle may be beneficial because of the higher output of muscle power and/or the larger storage of oxygen bound to myoglobin in the muscle. The large size of the pectoral muscle in the Emperor Penguin reflects its requirement for deep and long diving rather than rapid swimming. We could find little difference in swimming velocities between Emperor and Adélie penguins (7.5 and 7.2 km/h, respectively; Kooyman et al. 1987); the large pectoral muscle of Emperor Penguin seemed not to work efficiently for swimming. However, because of obvious differences in maximum diving depths (265 and 80 m, respectively; Burger 1991), the larger pectoral muscle probably can store more oxygen. The allometric relationships of morphology and diving function to body size were not considered because more specimens would have been needed for such an analysis.

The body cavity of the Adélie Penguin, in proportion to its body volume, was about twice as large as that of the Emperor Penguin (43.19 and 24.49%, respectively). It is possible that the larger body cavity could be associated with greater food intake. However, because each organ in the body cavity was not clearly distinguishable in the CT images, we were not able to analyze this possibility in detail.

The subcutaneous tissue of the Emperor Penguin was proportionately much larger than that of the Adélie Penguin (15.45 and 5.63%, respectively). The subcutaneous tissue may vary seasonally and may be influenced by starvation during chick rearing. Therefore, our measurements may not represent specific differences between the two species because specimens were not obtained at the same time of year.

In conclusion, CT scanning can provide detailed information on internal morphology of birds the size of penguins. The technique may be useful in a number of different avian morphological studies.

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Roseate Tern Trio Fledges Three Young

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Fitch and Shugart (1983) reviewed reports in the literature of trios in a number of species of larids, and Hemmings (1989) discussed breeding success of trios in the Brown Skua (*Catharacta lonnbergii*). Smith (1975) noted multiple birds at a number of nests of Sandwich Terns (*Sterna sandvicensis*), most of which were three years old; in none of the cases for this species did the multiple relations continue until the eggs hatched.

In this note I will discuss a Roseate Tern (*S. dougallii*) nest I found on Great Gull Island in 1991, where three adults incubated three eggs and raised three young. Roseate Terns nest on both sides of the North Atlantic.