SOME FIELD TECHNIQUES FOR ECOLOGICAL RESEARCH ON EMPEROR PENGUINS

APTENODYTES FORSTERI

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SUMMARY

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This paper describes the following techniques for conducting ecological research on Emperor Penguins *Aptenodytes forsteri*: capture and restraint, measuring body masses, marking individuals for identification, collecting stomach contents, preventing liquid radio-isotopes from freezing in sub zero temperatures, handling adults during incubation and brooding, withdrawing blood samples and attaching dive recorders. The techniques described are of particular relevance to field research conducted during the Antarctic winter.

INTRODUCTION

The Emperor Penguin *Aptenodytes forsteri* is by far the largest and most powerful seabird. Adults stand as tall as 115 cm and weigh up to 40 kg at the beginning of the reproductive cycle (Prevost 1961). The species breeds through the Antarctic winter under the most severe weather conditions experienced by any bird, with ambient temperatures as low as -35°C and even -60°C when wind-chill is considered. Because of the severity of the Antarctic winter the Emperor Penguin is probably the most difficult species of penguin to study, for the conditions they experience must also be faced by the researcher.

Many of the field techniques considered to be standard in ecological research for other species of penguin involve an added degree of difficulty, particularly for the inexperienced researcher, when applied to Emperor Penguins during winter. The practical nuances of research methodologies are rarely reported, yet they have an important bearing on the outcome of field research on Emperor Penguins and may even limit the scope of the research at the planning stage.

The purpose of this paper is to describe methods adopted during a comprehensive study of the feeding ecology of Emperor Penguins. The study sought information about the birds' diet composition (by stomach flushing), food and energy consumption (by isotope turnover) and foraging parameters (by attachment of time-depth recorders and radio transmitters) during 1988 at the Auster (67° 23'S, 64 02'E) and Taylor Glacier (67° 28'S, 60 53'E) colonies near Australia's Mawson Station (67° 36'S, 62 53'E). The methods described are intended to minimize stress experienced by Emperor Penguins when handled, reduce personnel requirements in the field and increase the efficiency by which research questions can be answered. The difficult task of counting Emperor Penguins, an important part of ecological research on this species, will be considered in a later paper.

DESCRIPTION OF TECHNIQUES

Catching and restraining Emperor Penguins

Totals of 572 adults and 443 chicks were caught for various reasons during the study. To minimize disturbance to the colony, whenever possible adults were caught several hundred metres to seaward of the colony as they travelled to or from the ice edge. Individual adults were caught by tackling them rugby-style (taking care not to land on the bird) as they tobogganed on the sea-ice. Most penguins were caught after pursuits of less than 25 m; longer chases were abandoned for fear of unduly stressing the birds. An alternative and perhaps less stressful method of capture would be to immobilize the penguin in the standing position with a shepherd's crook attached to a 2-m long handle (G.L. Kooyman pers. comm.). Once stationary the penguin can be approached by the researcher and physically restrained.

When many adults were required they were caught by herding them into an enclosure made from sections of a portable sheep yard (McShane, Australia) which is self supporting when erected, light in mass, easily built and collapsible. These features meant that an enclosure of almost any shape (including circular, which allowed the birds to move unimpeded by corners) or size could be quickly and easily built. The yard consisted of numerous detachable panels, each of two hinged 1.9 x 1.0 m sections weighing 23 kg. Since Emperor Penguins are inclined to follow one another when moving on the sea-ice two or three people could shepherd groups of 20 or so birds into the yard at a time. Créche-stage chicks were caught by assembling sections of the sheep yard around them as they huddled on the sea-ice. Single chicks were caught with a long handled (3 m) butterfly net.

Following their capture, the penguins were restrained for experimental purposes in a heavy duty cone-shaped canvas bag (Fig. 1). Adults less than *c.* 30 kg were restrained in a bag 80 cm in length and 18 cm and 50 cm in diameter at the narrow and wide ends, respectively. The bag for pre-incubation males and moulting birds, which were fatter than adults feeding chicks, exceeded these measurements by 2 cm and 5 cm at the narrow and wide ends, respectively. Each bag was slightly oversized so if necessary it could be folded over the restrained bird's head to cover its eyes, which tended to subdue it. The ends of the bag were reinforced by rope sewn into the canvas and metal eyelets were placed around the wide end as attachment points for weighing scales. Chicks up to about 1 kg (*c.* 2 weeks of age) were handled in a calico bag; those between 1 kg and 3 kg were restrained in bags as for adults, but 50 cm in length and 12 cm and 30 cm in diameter at the narrow and wide ends, respectively.

Weighing Emperor Penguins

Emperor Penguins can be weighed by suspending them from a scale by hand, from a scale under a tripod (Klages 1988), or by standing them on a platform balance (Le Maho *et al.* 1976). Because of their height and mass Emperor Penguins are difficult to suspend and the procedure usually requires more than one person. The one-person weighing system (Fig. 1) consists of a 1.5 m long metal bar placed over the operator's shoulder and joined by a rope to a foot plate anchored to the sea-ice by the mass of the operator. The penguin is slung from weighing scales positioned in front of the operator as shown in the figure. The technique was particularly useful when the body masses of large numbers of penguins were required (e.g. mass of arrival or departure).

To reduce stress on the birds during handling it is important to restrain Emperor Penguins in postures that are natural to them, either upright on their feet or prone on their ventral surface. Penguins restrained on their backs struggled more vigorously than those held in the postures above, and this could be expected to have increased the trauma experienced by the birds.

Figure 1

A one-person weighing system for Emperor Penguins.

Marking Emperor Penguins for identification

For identification purposes adults were marked with a numbered aluminium flipper band, and the feathers on their ventral surface (above the snow line when they tobogganed on the sea-ice) was sprayed red with 'Super Enamel' paint (Dulux Australia Ltd.). During the colder months the paint froze moments after application but even so residues of it were still evident, as a pink flush through the plumage, up to 60 d later when the penguins had completed at least two foraging trips at sea. The frozen paint was ignored by the birds and presumably had little effect on the insulation properties of their feathers. In summer, however, the paint did not freeze on application and the birds attempted to preen it from their feathers. Therefore this type of marker is probably useful only in temperatures low enough to ensure the paint freezes quickly when applied. Nyanzol-D (Belmar Inc., Massachusetts, USA) might be a more suitable marker since it reputedly does not affect feather structure and has lasted at least 2.5 months on foraging Emperor Penguins (G.L. Kooyman pers. comm.).

The flipper bands used were designed specially for use on Emperor Penguins and were suitably loose on adults during the incubation and chick feeding stages of the reproductive cycle, but scarcely fitted around the swollen flippers of moulting adults. Since bands of the correct size would be too large for non-moulting penguins conventional flipper bands should not be used as a permanent marker for Emperor Penguins. Flipper bands could probably be used as temporary markers on foraging birds provided they can be removed well before the moult cycle commences. Note, however, that the chances of recapturing banded birds late in the chick-rearing period will be low, because Emperor Penguins attending large chicks spend most of their time at sea feeding and visit the colony to feed their chick for a few hours only. Furthermore, they may not return to the colony at predictable time intervals, especially if they were traumatized by capture and handling during the experimental procedure.

In studies where it is necessary to band temporarily moulting penguins the bands should be designed to accommodate the bandable portion of an Emperor Penguin's flipper of these dimensions (mean values, s.d. in parentheses, n=4): circumference 134 (4.8) mm, width 56.2 (2.8) mm, thickness at leading edge 22.3 (2.8) mm and thickness at trailing edge 15.9 (2.6) mm. These measurements were of flippers where the swelling appeared to have peaked, and a comfortable band should exceed these dimensions by at least 2 mm.

The flippers of experimental chicks were temporarily marked for identification with Velcro hook and loop nylon fasteners (Linkron Pty Ltd, Australia). These come in a range of bright colours that are easy to see in the colony, are adjustable to accommodate flipper growth and can be numbered with a felt-tipped pen.

Procuring stomach contents

During this study 170 adult Emperor Penguins were stomach flushed for an analysis of diet composition using the water-flushing technique of Wilson (1984). To flush their stomachs I used a manually operated Handy Pump (Marshall Electronics Inc., USA), although any pump capable of pumping water would probably suffice (see Wilson 1984). The seawater was heated to *c.* 20°C in a bucket with a high pressure gas burner and during the colder months of the year the pump was kept in the bucket throughout the operation to prevent the water in it from freezing. Water was pumped into the penguin's stomach through a 10 mm diameter (7 mm internal) Tylon (Imamura Rubber Co., Ltd., Japan) tube which was extended 90 cm from bill tip to stomach. PVC plastic tubing was too brittle in the cold and silicone tubing was too soft.

With the water-flushing technique it is especially important not to overfill the penguin's stomach. Of the 170 adults stomach flushed four died (a further three were distressed to the extent that the procedure was abandoned and the birds released) from ruptured stomachs due to overfilling. Too much water was introduced because the food mass (and, in the case of subsequent flushings, food and unregurgitated water), and therefore the volume remaining to capacity, was not properly considered. The mass of food in an Emperor Penguin's stomach not only varies seasonally but between birds within a season (G.G. Robertson unpubl. data), which makes it difficult to rely on results of previous sampling to estimate the free space in a penguin's stomach. In spite of this, the bird's life will not be jeopardized if the food mass is manipulated through the wall of the abdomen (to gain an appreciation of stomach fill) before each episode of stomach flushing, and if the volume of water introduced is conservative. Filling birds until overflowing (e.g. Offredo & Ridoux 1986, Klages 1989, initial birds sampled here) leaves no margin for error should the penguin resist the urge to regurgitate. In this event the only warning the bird's stomach may be reaching capacity and may rupture is the back pressure felt in the pump, which may be minimal and would require an alert operator to detect. The risk to the penguin might be reduced by restraining it in the horizontal position, thereby reducing the pressure head of water in its stomach.

As a general guide females returning to the colony at the commencement of chick feeding in July with a mean wet food mass of 1027 g (n=24 birds) in their stomachs were flushed with up to 5 l of water, and in December adults that were returning with a mean of 2174 g (n=12) of food in their stomachs to feed chicks two weeks prior to fledging were given up to 3.5 l of water. These estimates are conservative, since they are based on the largest food mass for each period, not on the mean food masses shown above.

A penguin inverter (Fig. 2) was developed to reduce operator effort and stress on the birds during stomach flushing operations. The inverter is a metal frame supporting a cradle shaped to accommodate an Emperor Penguin (i.e. wide at the base, narrow at the top). The cradle is lined with a mattress of sponge rubber embedded in canvas (which prevents the bird from destroying the sponge with its feet) attached to the cradle by cable ties to protect the bird and supported on either side by a stub axle around which it can pivot through 180°. A locking device on the side nearest the operator locks the cradle in either upright, horizontal or inverted positions. The uprights are joined by a foot plate which prevents the bird from falling out of the cradle when in the upright position. In practice Emperors rarely stood on this, preferring instead to cling by their toes to the bottom rung of the cradle. The penguin is held in the cradle by four webbing straps which pass over the bird's back from one side of the cradle to the other, and fastened by Velcro. The vertical positions of both foot plate and cradle in the frame can be adjusted to suit the operator, and the cradle and uprights can be removed for transporting.

To operate the inverter an Emperor Penguin, restrained in a bag, is placed in the cradle locked in the horizontal position. The cradle is then pivoted into the upright position and the stomach of the bird filled with warm water adopting the normal procedure for the water flushing technique. When enough water has been administered the tube is removed and in a single movement the bird is rotated through 150° over a bucket. With both hands the operator holds the bird's bill open, extends the neck and massages with a finger the sphincter inside the bird's throat to allow free passage of the stomach contents. At the same time a second operator, usually the person pumping the water, applies pressure to the bird's stomach (upside down at this stage) through the open end of the bag. The penguin then disgorges its stomach contents into the bucket.

The advantage of the inverter over more conventional methods is that it supports the bird's mass, is less tiring for the operator and completely immobilizes the penguin, thereby eliminating the time spent restraining the bird. This halves the time spent flushing the stomach, reduces the trauma experienced by the bird and requires only two people instead of three. The inverter would be most suitable for use on Emperor Penguins, because of their size and strength, but could be used effectively on King Penguins *A. patagonicus*, which are also large and difficult to restrain. In addition the inverter can be used to restrain birds during the attachment of dive recorders and other devices to their plumage, and with minor modification to the cradle to allow access to a flipper could be used to restrain birds while blood samples are taken.

Keeping radio-isotopes liquid in sub zero temperatures

Tritiated water ($^3H_20$), sodium-22 (^{22}Na) and Oxygen-18 are used commonly on seabirds to estimate their rate of food and energy consumption (Green & Gales 1990). Water is used as a carrier for these isotopes and they are usually transported in the field in glass bottles shielded by tin or lead. When used in Antarctica, where ambient temperatures in winter often fall below -30°C, liquid isotopes must be treated with special care to prevent them from freezing, which could lead to breakage of the glass containers and contamination of the surrounding environment.

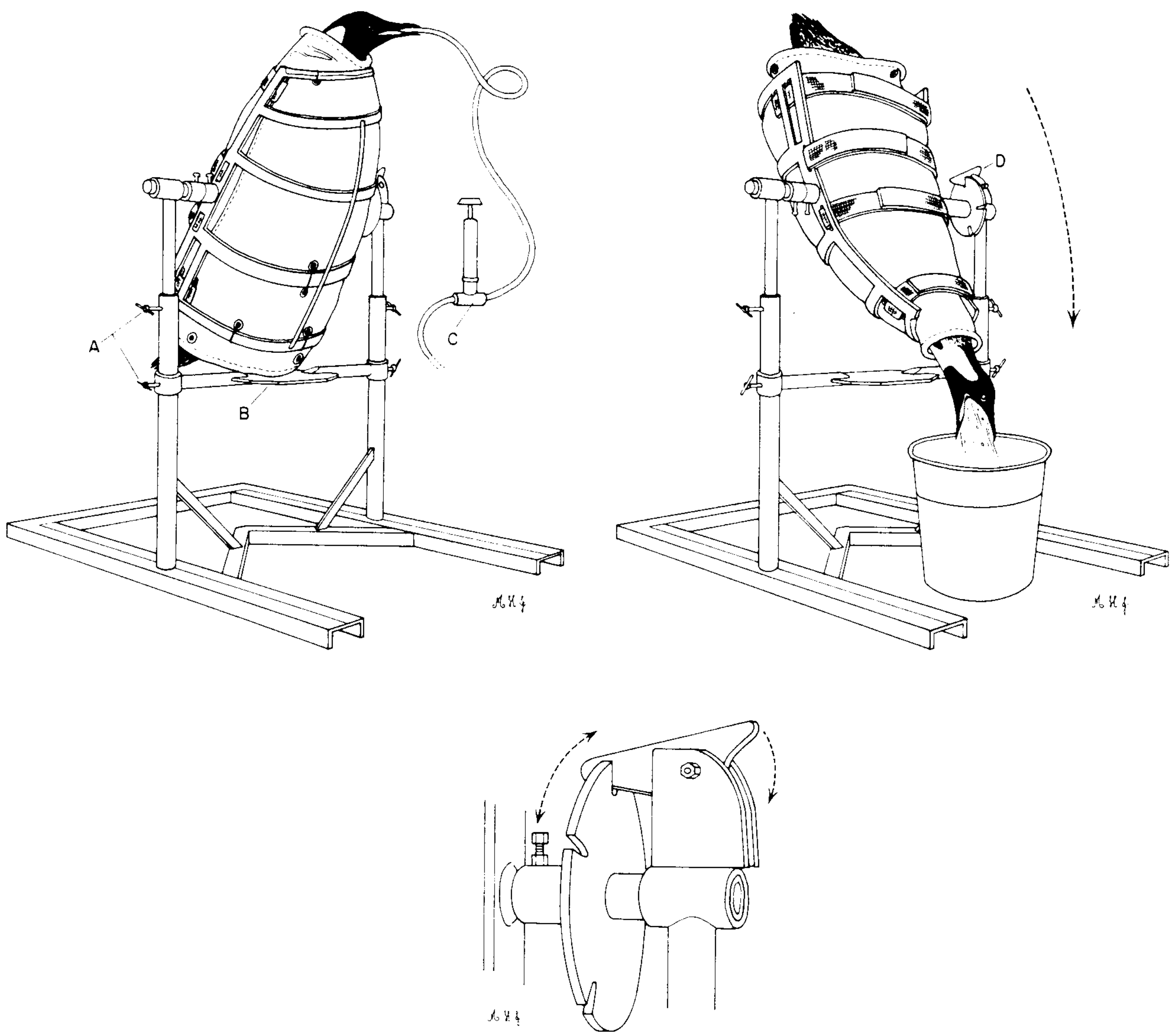

Figure 2

The penguin inverter showing an Emperor Penguin in the upright and inverted positions. Lettering shows points for adjustment or detachment (A), foot plate (B), stomach pump (C) and the cradle locking device (D). The inset shows an enlarged view of the device that locks the cradle of the penguin inverter with the broken arrows indicating direction of rotation.

The isotopes were prevented from freezing by housing them in a heated wooden box. The 50-cm square box was made of 12-mm marine plywood and lined with 10-cm of polystyrene foam. The bottles were contained in a 20-cm square core in the centre of the box and this area was encircled by 20 m of Auto Trace (Chemelex, USA) self-limiting heater strip (thermal rating 24 W/m) which was connected to a portable generator. Heating the central core for just 20 minutes per day maintained the isotopes above 5°C. An 8-kg brass disc, which could be heated on a camping stove, was embedded in the polystyrene under the isotopes in case the generator failed.

Inside the box the isotopes were shielded in pots made from 15 kg of lead (which themselves retained heat) with a central core large enough to hold a 100-ml glass bottle of sterile water commonly used to dilute isotopes to working strength. The 25-mm thick walls of these lead pots cut the emission strength of ^{22}Na, an emitter of gamma radiation, by a factor of twenty.

Handling incubating adults

Incubating males were injected with tritiated water, weighed and blood samples and body masses taken serially after release to estimate their rate of mass and fat loss during the incubation fast. Initially six males were weighed in the inverted position and restrained on their backs to draw blood samples from the ventral surface of the flipper. This procedure caused all the birds to struggle violently and lose their egg; three birds stepped on their egg during restraint while three birds retained their egg but were distressed by handling to the point that they abandoned it on release.

Egg loss, and presumably the stress experienced, was reduced by handling the penguins in the upright position. The bag was placed over the bird and tied off beneath it, taking care not to displace the egg from the penguin's feet. The bird was then weighed by attaching the scales to the top of the bag. Of 10 birds handled in this way eight retained their egg; the remaining two birds overbalanced during handling which caused them to spread their legs and lose their egg. An alternative method would be to weigh incubating males on a platform balance (Jarman 1973, Le Maho *et al.* 1976), which would eliminate the need to lift them from the ground. Whichever technique is used, egg loss can probably be reduced if the penguins to be weighed are selected by subjective appraisal of their temperament, as discussed below for Emperor Penguins brooding small chicks.

Regarding eggs abandoned during handling, male Emperor Penguins would rarely retrieve an egg if it was simply placed on the sea-ice a few metres in front of them. Of six birds that abandoned their egg when handled, five retrieved their egg when it was rolled across the sea-ice between their feet. This prompted the bird to scoop the egg onto its feet and into its brood pouch with its bill. Egg rolling was carried out inside the enclosure (so adults could not mingle with others in the colony) on smooth sea-ice with the person rolling the egg prone so the receiving birds attention would be focused more on the egg than on the person rolling it.

Handling adults brooding chicks

To estimate food and energy consumption of brood-stage chicks with isotopically labelled water, chicks were taken from their parent's brood pouches on three occasions (i.e. for isotope injection and to collect two subsequent blood samples). However, removing chicks distressed the brooding adults and they would not recover their chick on release. In July and August abandoned chicks died from exposure in a few minutes.

Subsequently, brooding adults were selected from the colony by subjective appraisal of their temperament while herding them into the enclosure, and by their reaction once in the yard; only birds that appeared to be "good parents" were selected. Typically these birds were in good body condition, shuffled slowly over the sea-ice even when prompted to move more quickly, paid repeated attention to their chick by bowing toward it and vocalizing, reacted aggressively to the person shepherding them and were not obviously distressed by being locked in the yard. Once in the yard adults were restrained in the standing position with the bag over their upper bodies while the chick was removed from their feet. Of 17 adults selected in this way 15 endured three bouts of chick removal and replacement, and appeared to feed their chick normally throughout the eight-day duration of the experiment. Note, however, that this selection procedure may result in a bias towards older, more experienced breeders and may yield results that do not necessarily represent the chick-feeding behaviour of the adult population (see below).

As a precautionary note, Emperor Penguins are particularly sensitive to disturbance during the incubation (when the male carries the egg on its feet and huddles with other males to conserve body heat) and chick brooding stages of the reproductive cycle. Disturbing incubating males can separate huddling birds, thereby releasing entrapped heat, and cause eggs to be lost if the birds are prompted to walk too quickly. During brooding, which extends for about two months from hatching, adults accidentally frightened into walking too quickly may spill their chick onto the sea-ice where it may freeze to death or be captured by a nonbreeding bird, only to be abandoned later and die (Jouventin 1975). Special care should be exercised by researchers and expeditioners when visiting Emperor Penguin colonies during these two stages of the reproductive cycle.

Collecting blood samples

As for other species of penguin, blood samples from Emperor Penguins are usually drawn from veins beneath the ventral surface of the flipper (Groscolas, *et al.* 1975, Le Maho *et al.* 1977) or from vessels in the foot (G. L. Kooyman pers. comm.). Blood vessels in the foot, however, are hidden beneath a thick layer of skin, are constricted in winter and must be found by association with external features of the foot; these features must be learnt beforehand by dissecting the foot of a dead penguin. Thus the efficacy of this technique will depend largely on the experience of the researcher. On the other hand the blood vessels beneath the ventral surface of the flipper are prominent, even in extremely cold weather.

The flippers of several dead Emperor Penguins were skinned to examine the position of arteries and veins (Fig. 3; see also Trawa 1970). Externally, the brachial artery at the proximal end of the flipper appears as one large vessel, but is in fact an anastomosis of that artery. Attempts to place a needle in the lumen of one of these blood vessels failed because the vessels are narrow and mobile, and the needle usually rolled off their walls into the spaces between them. The easiest vessels to draw blood from in adults were the radial vein and marginal vein (Fig. 3). This is best done inside a hut or some other shelter by two people, one holding the penguin upright with a bag covering the head and torso, and the other drawing blood.

Emperor Penguin chicks up to about four months of age were more difficult to bleed than adults because their blood vessels were unobtrusive, even when the down was removed. Blood samples from chicks were drawn from either the radial artery or radial vein, which lie in intimate association in the groove between the radius and ulna. Due to the closeness of these vessels the artery was occasionally punctured, but this did not seem adversely to affect the chick. Approaching the vein with the needle at a slightly oblique angle minimized the chances of the needle rolling off the wall of the vein.

Attaching dive recorders to foraging birds

Adhesives (Heath 1987, Gales *et al.* 1990), tape (Wilson & Wilson 1989), Velcro (Heath 1987) and worm-drive hose clamps (Kooyman *et al.* 1982, Lishman & Croxall 1983) have replaced harnesses (Wilson & Bain 1984) as the preferred methods for attaching dive recorders to the feathers of penguins foraging at sea because they impose less of a hindrance when the birds are diving. However, the reliability of these attachment methods could vary with the species of penguin and the environment in which it forages. In this study dive recorders were attached with both adhesive and clamps because other methods of attachment may not have withstood the rigours of the Emperor Penguin foraging regime (i.e. extended periods at sea, dives in excess of 400 m and swimming among pack ice).

To test the bonding strength of adhesives in temperatures below those normally required for optimal curing, dummy dive recorders were attached to the feathers of a dead Emperor Penguin and frozen. The adhesives used were cyanoacrylates (Loctite 401, 405 and 'Supaglue'), two-part epoxy resin (5-minute and 24-hour Araldite) and latex-based adhesive ('Kwik grip' and 'Bostik'). Adhesives were allowed to cure for three minutes (an approximation of the curing time in the field) at 5°C before being frozen to -30°C for two hours.

The devices attached with the cyanoacrylates and epoxy resins were more difficult to remove from the feathers than those attached with the latex-based adhesives. The difference between the cyanoacrylates and epoxy adhesives was minor; overall however, Loctite 401, described by its manufacturer as a surface-independent, ultra-fast instant adhesive, achieved a slightly stronger bond than the others, and was chosen for subsequent use in the field.

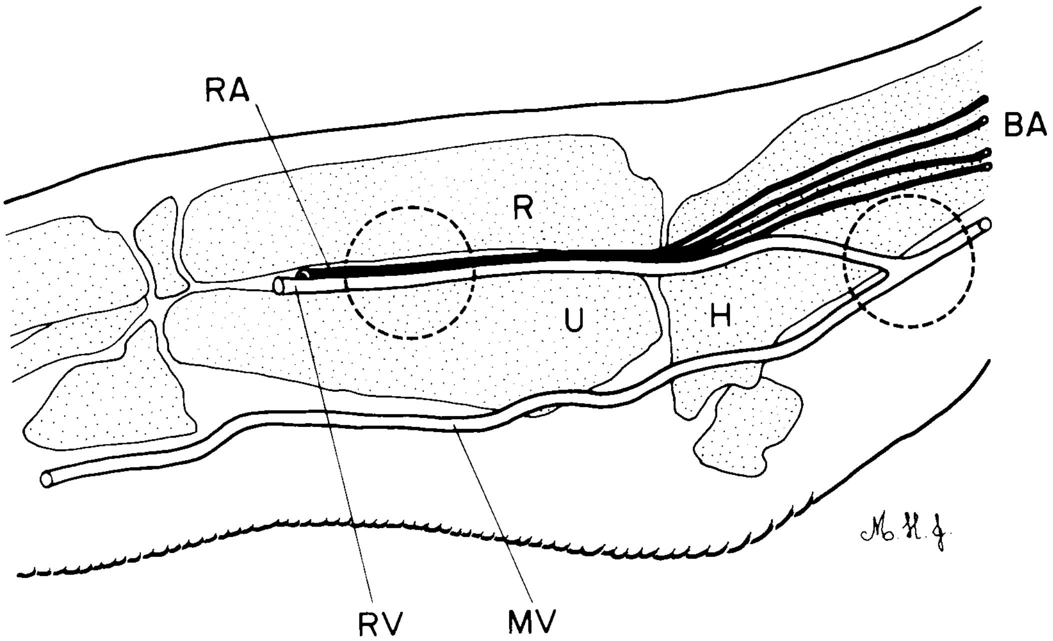

Figure 3

Simplified version of the main blood vessels in the ventral surface of an Emperor Penguin's right flipper. Stippled areas show the radius (R), ulna (U) and humerus (H). Vessels shown are an anastomoses of the brachial artery (BA), radial artery (RA), radial vein (RV) and the marginal vein (MV). The circles indicate prefered sites for drawing blood samples

Dive recorders were attached to the feathers 15 cm above the tail with four light weight (7 g) worm-drive hose clamps (one on each corner of the device) and Loctite 401 adhesive. To locate the birds on their return to the colony a small radio transmitter was glued to the feathers between the shoulders and an area of the bird's plumage was painted as described above. Of 57 dive recorders deployed on penguins between July and December, 31 birds returned to feed their chicks, each with devices firmly in place even though some penguins spent up to 65 d at sea and dived below 400 m.

The remaining experimental penguins presumably abandoned the colony as no marked penguins were found without dive recorders despite intensive searching nearly every day of the sampling period. The abandonment rate (devices lost as a percentage of the number deployed) increased through the chick growing period, and ranged from 0% (n=10) in July (males, post-hatching), 20% (n=10) in early September, 44% (n=18) in mid October and 89% (n=19) for birds captured during the first two days of December. This trend does not follow the pattern of chick mortality (Robertson in press) so the experimental birds being released from parental duties cannot explain why many adults carrying devices abandoned their chicks. Presumably the failure of these birds to return to the colony reflects, at least in part, their reaction to the trauma of capture, handling and attachment of devices (see also Wilson *et al.* 1989, Gales *et al.* 1990).

One way of minimizing the effect of this problem would be to select for foraging behaviour studies the least timid birds, for these are usually the easiest on which to conduct experiments (Le Maho *et al.* 1977). Typically, instead of tobogganing away when approached by people these individuals remain upright and vocalize vigorously during attempts to capture them. However, where estimates of ecological parameters are to be extended to the population, a random method of selection would be necessary, and the importance of this must be weighed against the risk of investing expensive devices in birds that may be distressed by handling to the point where they abandon the colony on release.

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