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Authors: Adrian C. Gleiss, Brad Norman, Nikolai Liebsch,
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A new prospect for tagging large free-swimming sharks with motion-sensitive data-loggers

Adrian C. Gleiss[1*], Brad Norman[2], Nikolai Liebsch[1], Clive Francis[3] & Rory P. Wilson[1]

[1]* Institute of Environmental Sustainability, Biological Sciences, Swansea University, Singleton Park, SA1 8PP, UK

[2] ECOCEAN Inc., *c/o* Centre for Fish & Fisheries Research, Murdoch University, South Street, Murdoch, WA 6150, Australia

[3] School of Engineering, Swansea University, Singleton Park, SA1 8PP, UK

*Corresponding author. Email: 323246@swan.ac.uk

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Running head: tagging large sharks

Abstract

Sensor types in animal-attached tags (e.g. accelerometers, speed sensors and compasses) now often require devices to be solidly attached to an animals' body, which would preclude their use on many large species of shark where current attachment systems are based on tethers. A new method of attaching motion-sensitive tags securely to large sharks is presented which allows free-swimming animals to be equipped without any form of restraint. The system was tested on 11 free-swimming whale sharks (*Rhincodon typus*) at Ningaloo Reef, Western Australia. Devices were placed on one of two elongated arms emanating from a torsion spring which acted to force the arms together. The system was clamped to the second dorsal fin using a specially-designed tagging-gun operated manually by a snorkeller. Each arm was equipped with two 1.5 cm-long spikes to ensure stable, firm attachment to the fin. Data from the deployments showed that response to the tagging event varied between individuals, with some sharks showing no obvious reaction, while others exhibited a substantial reaction. Clamps remained stable on the sharks throughout the entire duration of all trials. The whole system was fitted with a corroding magnesium link to ensure that the clamp would release from the shark within weeks of deployment.

Introduction

Many species of shark are in severe decline worldwide and their conservation is becoming a major focus in ecosystem management (e.g. Baum et al., 2003; Stevens et al., 2000). Data on the movement and behaviour of the species concerned are critically required so that management plans can be implemented appropriately (Southhall et al., 2006). Typically, such data can be gathered using electronic devices attached to the animal, which either transmit or archive a wide range of information (e.g. Sims et al., 2003; Weng et al., 2005).

Due to the inherent difficulty of capturing and restraining large sharks, common tagging techniques involve darting animals with tags attached to a tether of variable length using either poles (e.g. Weng et al., 2007) or spear-guns (e.g. Gunn et al., 1999; Gifford et al., 2007). These techniques have proven very successful for attachment of a variety of tags to a number of species of free-swimming shark, including PAT tags (e.g. Sims et al., 2003) and acoustic tags (Gunn et al., 1999) or PTTs (Eckert and Stewart, 2001).

In light of the technological advances in the field of data-logging, sensor types contained in many tags have diversified drastically and include, for example, accelerometers, imaging-systems, compasses or speed sensors (for review see Cooke et al., 2004; Ropert-Coudert and Wilson 2005). These sensor types have widened the scope of investigations into animal ecology and behaviour through their potential to measure key variables, such as activity-specific metabolic rate (Wilson et al., 2006) or behavioural traits (e.g. Kawabe et al., 2003; Shepard et al., 2008).

Many modern sensors (e.g. accelerometers, magnetometers) require solid attachment, something that can be implemented when animals can be sedated, such as is the case in pinnipeds (McMahon et al., 2000), or are small enough to be safely handled, e.g. in birds (Wilson et al., 1997) or smaller fishes (Tanaka et al., 2001). However, such sensors cannot be used attached to a tether as the motion of the tag distorts data recorded. As a consequence, many modern data-loggers which acquire information on animal orientation are not deployed on large sharks, such as whale sharks (*Rhincodon typus*), white sharks (*Carcharodon carcharias*) or basking sharks (*Cetorhinus maximus*).

This work describes a new system for attaching data-loggers to large sharks with a stable base. We document the behavioural impact of the system on instrumented animals and qualitatively assess the ability of an attached tag to record motion-sensitive high-resolution behavioural data.

Method

Tagging Equipment

The complete system consisted of a clamp and a tag package. The latter was made up of a multiple channel logger (the 'daily diary' – Wilson et al., (2008)) (80mm x 37 mm x 19mm, 66g in air) which was contained together with a 2-stage coded VHF Transmitter (Sirtrack, New Zealand) (48mm x 34mm x 38mm, 55g in air) and in 2008 continuous medium power-output acoustic transmitter (Thelma, Norway) in a positively-buoyant Micro-bubble and epoxy-resin housing (*cf.* Liebsch, 2006). The base of the housing was built with a protuberance so that it locked into a specially-constructed beam, welded onto a 20 cm long stainless-steel spring wire (diameter 5 mm) (the clamp, Fig. 1). The notch in the beam was located at the anterior end of the wire. The posterior end ran into a 2-turn spiral spring (spring diameter 5 cm) and continued out to another 20 cm long wire that ran approximately parallel to the arm on which the device was located (spring system constructed by Airedale Springs Limited, UK). Both arms were covered by titanium sleeves (15 cm long). Two short spikes (1.5 cm) had been welded onto each arm (Fig. 1). One spring arm was cut near the coil and was reconnected using a magnesium sleeve (Fig. 1) to act as a mechanism by which the complete spring-system would release from the fin following corrosion of the magnesium (estimated at approx. 3 weeks). The clamp weighed 137 g in air (density ~4.9 kg L^{-1}) and the combined weight of the buoyancy housing including tags was 224 g (density ~1 kg L^{-1}), giving a total weight of 361 g in air and 109 g in seawater.

Fig.1

The tag package itself had two mechanisms that enabled it to be released from the clamp. It had a protruding bolt at its posterior end, tilted forward at a slight angle to the longitudinal axis, which was connected to the spring via a Galvanic-Timed-Release (GTR, International Fishing Devices, USA). Thus, when corrosion of the GTR was complete, the tag-package would release itself automatically and a VHF transmitter incorporated would facilitate recovery if required. In addition, the tag package was held in place by a cotter-pin, through a short line of monofilament ending in a loop connected to the GTR incorporated in the clamp (Fig.1). It was therefore possible to manually release the tag even before complete corrosion of the GTR.

The clamp and tag-package was deployed using a custom-built tagging-gun, which held the spring open, creating the tension necessary for a secure attachment (Fig. 1). The tagging-gun consisted of a handle and trigger (including a safety-pin), an approximately 1.5 m shaft and the spring release system mounted perpendicular to the line of the shaft at the tip (Fig. 1).

The clamp was attached by positioning the spring arms either side of the shark’s fin and pulling the gun trigger. Release of the spring from the tagging-gun caused the spring arms to snap close around the fin, thereby pushing the spikes into the tough shark skin and cartilage and securing the device in a stable position.

Field Protocol

Whale sharks were located using a spotter plane off Ningaloo Reef (Western Australia – 22°00’S 113°50’E) before being cautiously approached in a rigid inflatable boat (RIB), where upon snorkellers entered the water to assess shark behaviour. If no immediate active avoidance was observed and snorkellers were able to approach the animal, tags were attached as described above. Devices were placed on the second dorsal fin (Fig. 2) using the tagging-gun operated by an individual ‘tagger’. Total length (TL) of each shark was estimated by comparing the known size of snorkellers alongside the shark *in situ* and from subsequent analysis of photographs taken of each shark.

Fig. 2

Visual observations of the behaviour of each shark immediately post-tagging was noted in as much detail as possible. In 2007, sharks were visually tracked from the air and the water before devices removed. If the animal dived and visual contact was lost, an immediate search pattern was employed until the animals were resighted whereupon observations were continued.

In 2008, sharks were tracked acoustically from a small RIB using a THELMA manual acoustic receiver and directional hydrophone. Distance to animals was variable (maximum range of transmitters tested on site = 1.4 km) but attempts were made to remain at least 400 m from the animal being tracked.

Analysis

Archived data from retrieved devices were downloaded and analyzed using custom-written software (Department of Computer Science, Swansea University) and Origin Pro (Origin Lab Corp., Mass., USA). Behaviour post-tagging was analyzed by calculating descent rates for dives after the animal was tagged and subsequently for the remainder of the track. A dive was defined as any period the shark swam from within 2.5 m of the surface and descended to at least 5 m. The end of a descent was defined as the period where depth either remained constant for a protracted time or depth increased.

The duration of initial disturbance of external device attachment can be quantified by analysing locomotory activity (Sundström and Gruber 2002); We therefore calculated tail-beat frequency (TBF) for a single animal that exhibited a substantial reaction and a second animal exhibiting minor reaction every two minutes, by counting peaks >0.1*g* in the swaying acceleration over a 20 sec period (*cf.* Tanaka et al., 2001), unless particular phases were shorter (see Results) whereupon shorter intervals depending on duration of the behaviour were employed.

Results

Deployments

A total of 11 sharks were tagged in 2007/2008 and clamps and tag-packages remained attached successfully for the intended length of deployment (minutes to hours) (Table 1). The first shark (*ca.* 6.5 m female) was tagged on 21 June 2007 with a 'dummy' device. This initial trial showed that the clamp remained apparently well-fixed to the animal after attachment and during a dive that lasted less than 10 min (the time until shark was resighted). Closer *in situ* inspection revealed the anterior two spikes had penetrated well into the fin whereas the posterior spikes had not penetrated due to the spring arms not tracking the cambered lateral surface of the fin (Fig. 3). Despite this, the complete system remained secured to the animal and appeared stable for the total observation time (50 min). Following this, one spring arm was bent inwards for the remaining trials to ensure that all four spikes penetrated the skin (Fig. 3).

Fig. 3

Although this adjustment generally increased the fit of clamps to the fin, significant variability in how well clamp arms accorded with the fin and the degree to which the spikes would penetrate depending on the size of the shark was evident. However, all clamps remained securely attached to each shark for the entire duration that animals were tracked and at no point did a clamp release prematurely. Deployment durations varied between 32 min and 7 h 15 min, with a mean duration of 2 h 28 min (Table 1). Data clearly show visible oscillations in the swaying acceleration according to tail-beat (Fig. 4; *cf.* Kawabe et al. 2003). Four of the clamps were manually removed by a snorkeller after tag-packages were released and subsequent observations of the second dorsal fin showed very little damage apart from small marks left by the clamp spikes (Fig. 4).

Fig. 4

Table 1

Direct Observations

The responses exhibited by sharks in the present study could generally be divided into three categories; i) sharks that exhibited a substantial reaction to the attachment of the clamp, mainly consisting of a number of pronounced tail-beats and the subsequent initiation of a dive; ii) sharks that initiated a passive dive after attachment; and iii) sharks that exhibited no immediate reaction (Table 1). Of the 11 sharks tagged, three animals exhibited substantial reactions, whereas 7 sharks initiated gradual dives upon tagging. A single shark showed no obvious signs to the attachment and continued traveling in the same manner as pre-tagging (Table 1). For sharks exhibiting substantial reactions, visual observations by snorkellers allowed the behavioural alterations to be divided into three separate phases: i) an immediate heavy reaction; ii) a period of heightened activity; and iii) behaviour resembling that observed prior to tag attachment.

Quantitative Observations

Sharks that exhibited a substantial reaction, also undertook significantly faster descent rates of 0.60 ms^{-1} (SD ± 0.12) in relation to animals that initiated a simple passive dive with descent rates of 0.26 ms^{-1} (SD ± 0.11) (Fig. 5; t-test: t = 4.19, $p>0.05$, df =3). This is further shown by a significant difference between animals diving after displaying a substantial reaction and subsequent "regular dives" performed after the initial tagging dive (Fig. 5; t-test: t-value= 5.01, $p>0.05$, df =2). Whereas sharks displaying minor reactions show no significant difference in their descent rates to "regular dives" (t-test: t-value= 0.04, p= 0.97; df = 4). To further investigate, this we determined activity levels exhibited by WS3, which showed substantial reaction to the tagging procedure and WS2 which exhibited only minor reaction to the tagging by initiating a dive. The immediate reaction of WS3 lasted 5 sec and was characterized by a TBF of 0.92 Hz. Following this, heightened activity was observed for a total of 42 sec and a calculated TBF of 0.48 Hz. The remainder of the track was characterized by a mean TBF of 0.28 Hz (SD ± 0.05). Both the immediate reaction and the heightened activity tail-beat values lie outside the 95% confidence interval. WS2 did not show any apparent reaction, supported by TBFs immediately after attachment (first 2 min) (TBF = 0.15 Hz) within the 95% confidence limit of the TBFs calculated for the remainder of the track (TBF = 0.14 Hz, SD ± 0.01).

Fig. 5

Discussion

This study set out to test a novel method of attaching motion-sensitive data-loggers to free-swimming sharks and qualitatively test its ability to record high-resolution behavioural data. Although these trials were conducted over short periods, our data, both qualitative and quantitative, demonstrate the potential of clamp-based systems (Fig. 4), similar to the first remotely-deployed suction cup tags on dolphins (Stone et al., 1994). Figure 4 shows acceleration signatures according to tail-beat which clearly resemble patterns obtained by other workers using direct attachment of accelerometers to fish (Tanaka et al. 2001; Kawabe et al. 2003; Gleiss et al. in press) which lends credence to our system.

Based on the stability of our clamp, we suggest that retention of this type of application system can be achieved at least for multiple days and potentially weeks. There appeared to be little or no movement of the clamp, even after the substantive reaction exhibited by three sharks, which would be expected to have increased drag and associated stress on the attachment. Close *in situ* observations revealed that the attachment appeared more solid after a 2 h period post-deployment, with each clamp spike penetrating entirely into the fin (cf. only *ca.* 80% penetration at time of deployment) (BN, pers. obs.).

Although this technique is not entirely benign due to the penetration of the spikes into the fin, no bleeding was evident (Fig. 6), likely due to the poor vasculerisation of shark fins. It is possible that the drag associated with such a relatively large system might result in the clamp slowly tearing along the fin, causing superficial tissue damage. However, due to the short length of each spike in relation to fin thickness, serious injuries appear highly unlikely. There was no evidence of such trauma (cf.

Fig. 6), even during the longest deployments. Clearly reducing hydrodynamic drag will decrease the risk of such potential deleterious effects and any design should strongly adhere to such approaches, especially in animals that are fast moving (Bannasch et al., 2006). Finally, as indicated by our own modification to the system between deployments on WS1 and WS2, it is imperative that researchers appreciate the morphometrics of the fin to which the tag is to be attached. The apparent variability of the fit of the clamps between individuals is likely due to differences in fin morphology so that, ultimately, flexible clamp arms might prove even more successful. A securely-fitting system would also be less likely to shift or dislodge completely and / or irritate the animal.

Fig. 6

The degree to which the presence of devices can alter the behaviour of sharks equipped can generally be divided into two categories: the trauma from attachment/handling and subsequent changes in behaviour until the animal becomes accustomed to the presence of the device and has recovered from the stress of interference (Sundström and Gruber, 2002), and lasting effects due to increased drag affecting performance (Blaylock et al., 1990; Grusha and Anderson, 2005).

Clearly, the tagging-event caused reactions in a number of animals, yet these reactions (if exhibited) are very similar to sharks reacting to human touch (Quiros 2007), and subsequent patterns of vertical movement are similar to those reported by Gunn et al. (1995) for whale sharks in the same area our study was based. We note too, that animals that exhibited a gently-sloping dive after being tagged performed similar descents later in the track (Fig. 5), whereas animals with a substantial reaction performed a single dive with a faster descent but return to gently-sloping diving patterns after this initial dive (Fig. 5). We therefore believe that beyond the first dive, all animals tagged showed natural behaviours which were only marginally, if at all, affected by the presence of the clamp.

The degree to which the clamp impaired performance of the sharks is difficult to assess from our data. In the past, Blaylock (1990) suggested that the mass ratio of the animal tagged (in his case a ray) and the tag should not exceed 3%. For a Whale shark, generally weighing in excess of 500 kg, this ratio is > 0.1%. This would suggest that the smallest animal that should be equipped with our package is 11.3 kg. However, as Grusha and Anderson (2005) correctly point out, buoyancy and drag, rather than mass, are the forces impairing performance. Drag requires measurement of forces acting upon the tag and subsequently on the animal, and could not be measured in this study. However, the small cross-sectional surface area of the tag-package (centimeters) in relation to the shark (meters) would suggest only minimal impact (cf. Bannasch et al. 1994). The impact of a change in the lift force, on the other hand, can be estimated by calculating changes in buoyancy induced by the tag. The buoyancy housing, including all components, is close to neutral buoyancy (albeit slightly positive), whereas the clamp is negatively buoyant. Therefore the shark's buoyancy will decrease as a function of carrying the clamp. Again, assuming a whale shark has weight in water of approx 2.5 % of its weight in air (this figure is for a blue shark (*Prionace glauca*), Bone and Roberts, 1969), then a 500 kg shark would change buoyancy by ~ 0.8 % while carrying the clamp. If we consider a 5% change in buoyancy a significant impact (Grusha and Anderson 2005), then the minimum size shark on which our device should be deployed is 85 kg, significantly larger than estimated by weight alone. Although these considerations provide rough guidance about the suitability of this method for different size classes of sharks, the power required to overcome drag could not be determined. Although we can assume that drag is minor in our application (due to the size of the subjects tagged), this might not be the case for smaller animals, where the device cross-sectional area is relatively larger in relation to that of the animal (Bannasch et al. 1994).

While few studies have been undertaken to assess the impacts of the tagging procedure on shark behaviour (Sundström and Gruber 2002) or the cost of carrying devices (Blaylock 1990; Grusha and Anderson 2005), future behavioural studies will benefit from an increasing quantification of these effects and provide increased confidence that any collected data is representative of natural behaviour, as well as only minimal costs incurred by the animal.

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Figure Captions

Fig .1 A) Schematic diagram of the clamp system (1) consists of a bouyancy housing consisting of a top (a) and bottom part (b), which encompass VHF transmitter (c) the logger (d) and an acoustic transmitter (e) .The tag-package is attached to the clamp (2) by sliding it over the clamp where a cut-out at the baseplate fits over a mounting beam (f), while a bolt at the front of the device is slid through a stainless-steal loop connected to the spring via a galvanic release system and fixed with a cotter-pin, leading to a line of monofilament for manual release (g). To create tension in the spring (3), it is opened (h) and fixed over two spring-holds on the tagging gun (i), where upon pulling the trigger the spring is released by one of the spring-holds retracting into the shaft (j). Magnesium sleeve releasing the entire clamp from the shark's fin (k). B) The tagging apparatus in the loaded, pre-deployment position (note the lack of the acoustic transmitter in the 2007 deployments).

Fig. 2 Location of the tagging system on a whale shark, *Rhincodon typus*.

Fig. 3 Differences in the shape of the clamp-arms and showing how this affected the snugness of fit of the attachment. A1 and A2 show straight arms which led to the rear spikes not penetrating into the fin, B1 and B2 show a slightly bent arm which led to both spikes penetrating well.

Fig. 4 Excerpt of data retrieved from WS5. Note the clear oscillations visible in the swaying (lateral) acceleration, coding for the side-to-side tail-beat motion, similar to other studies using direct attachments of accelerometers (Tanaka et al. 2001, Kawabe et al. 2003)

Fig. 5 Box-plot showing descent rates of dives immediately after a tagging event and during regular diving occurring after the initial dive. Tagging dives were further classified to animals exhibiting heavy and minor reaction according to Table 2.

Fig. 6 Photos taken while animal was equipped (A) and post clamp removal (B) after a 142 min deployment. Note the indentations resulting from the clamp and spikes with no evidence of bleeding or tearing.

Table 1 Details of all trails conducted.

Table 1

Shark ID	Date	Sex	Length (TL) [m]	Time tagged	Time retrieved	deployment duration [h]	Reaction	Method of Tag Release
WS1	21.6.2007	F	6.5	11:30:30	No device	00:50:00	Dive	N/A
WS2	22.6.2007	M	8.5	11:02:20	12:06:21	01:04:01	Dive	Manual
WS3	24.6.2007	F	4	10:57:14	11:29:15	00:32:01	Dive, multiple heavy tail-beats	Manual
WS4	20.05.2008	M	4	11:26:11	14:23:14	02:57:03	Dive	Manual
WS5	22.5.2008	M	9	13:16:36	13:45:14	00:28:38	Dive, single heavy tail-beat	Manual
WS6	23.05.2008	-	3.5	14:19:12	16:14:49	01:55:37	dive	Manual
WS7	24.05.2008	M	7.5	12:26:42	14:47:07	02:20:25	No reaction	Manual
WS8	26.05.2008	M	6	13:21:53	15:44:06	02:22:13	dive	Manual
WS9	27.05.2008	-	4.5	10:29:27	14:10:04	03:40:37	dive, multiple heavy tail-beats	Manual
WS10	28.05.2008	M	8	10:31:12	17:47:02	07:15:50	dive, single minor tail-beat	Automatic
WS11	29.05.2008	M	8	10:40:06	14:24:50	03:44:44	dive	Manual

Figure 1A

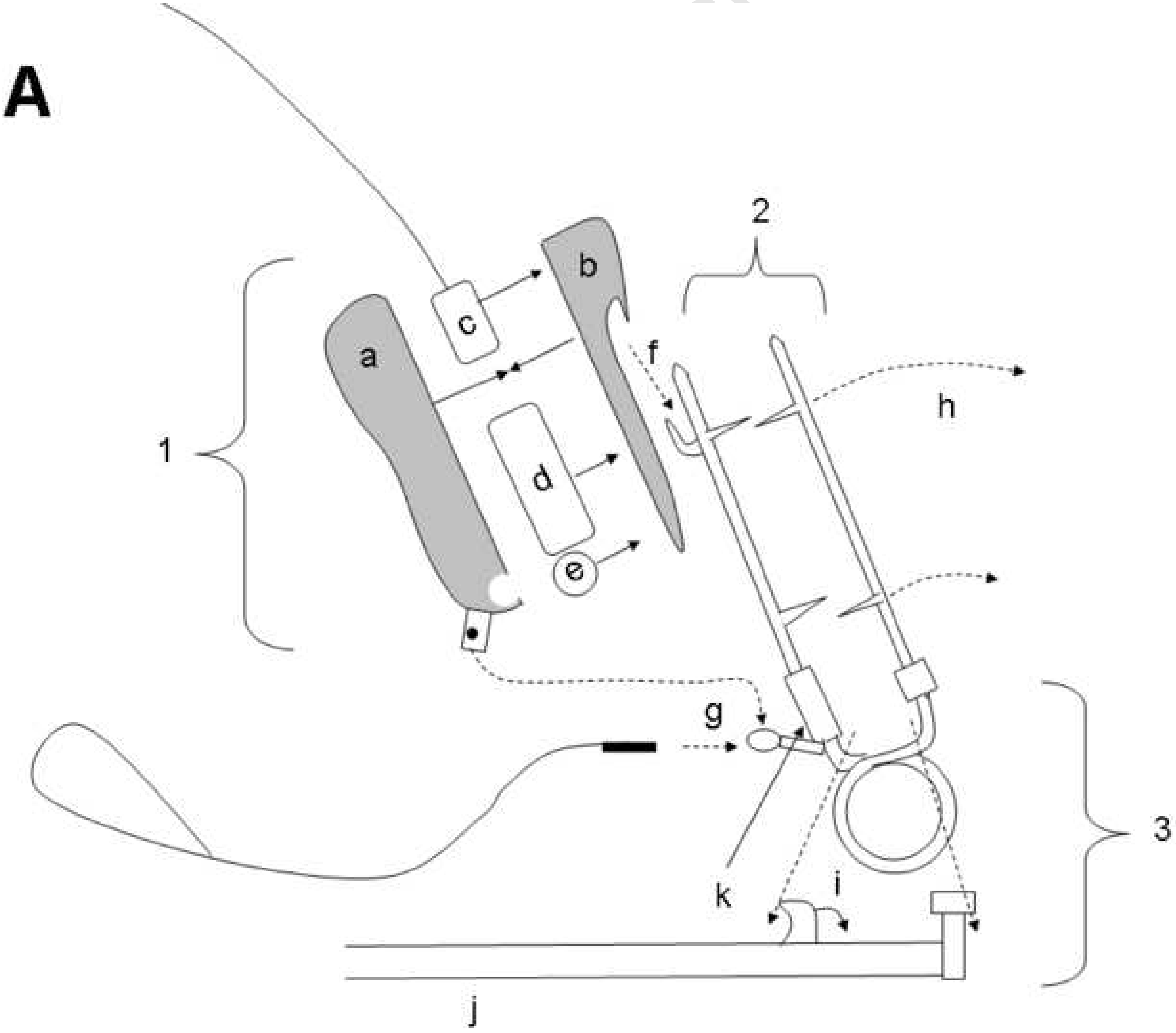

Figure 1B

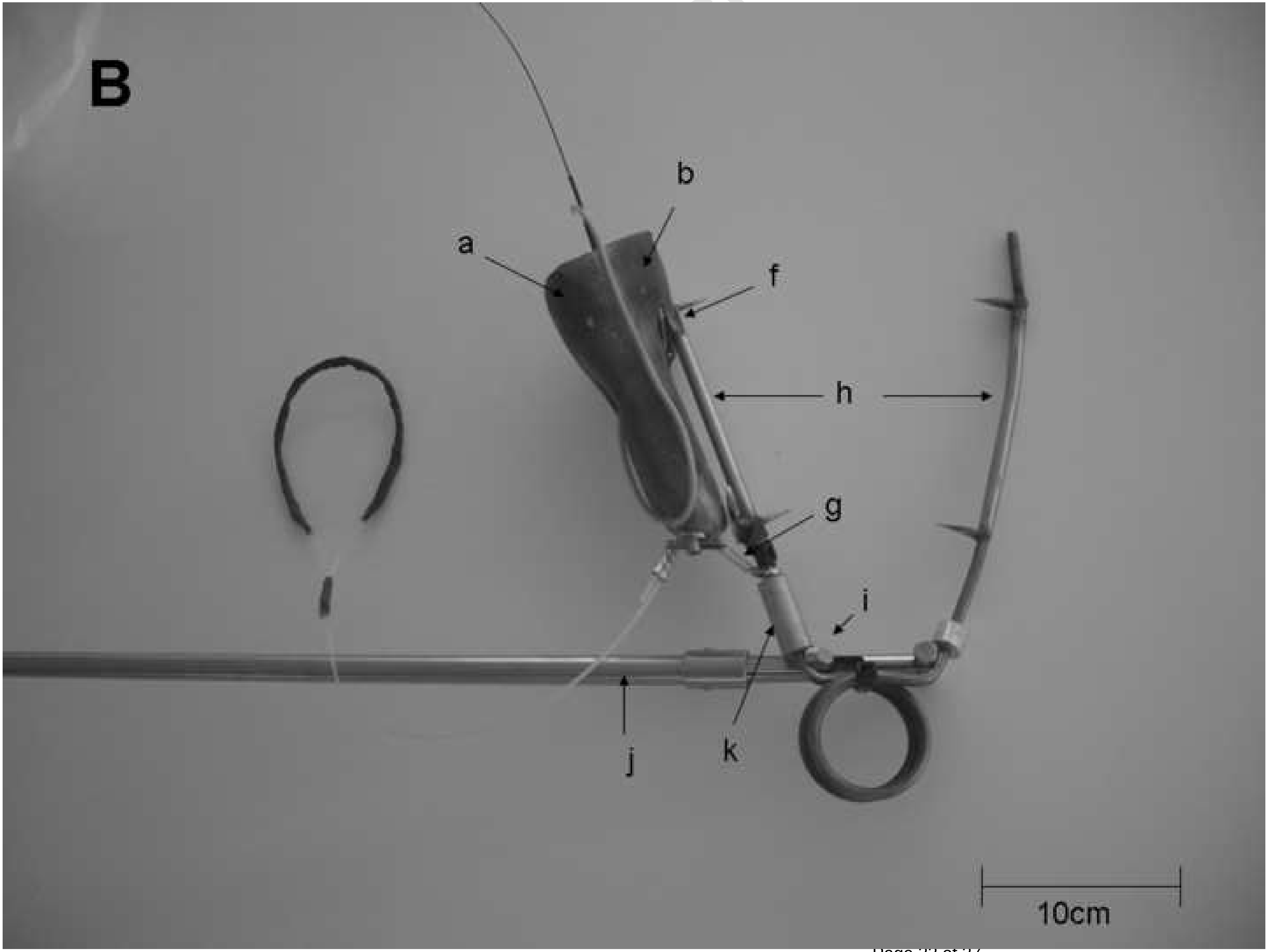

Figure 2

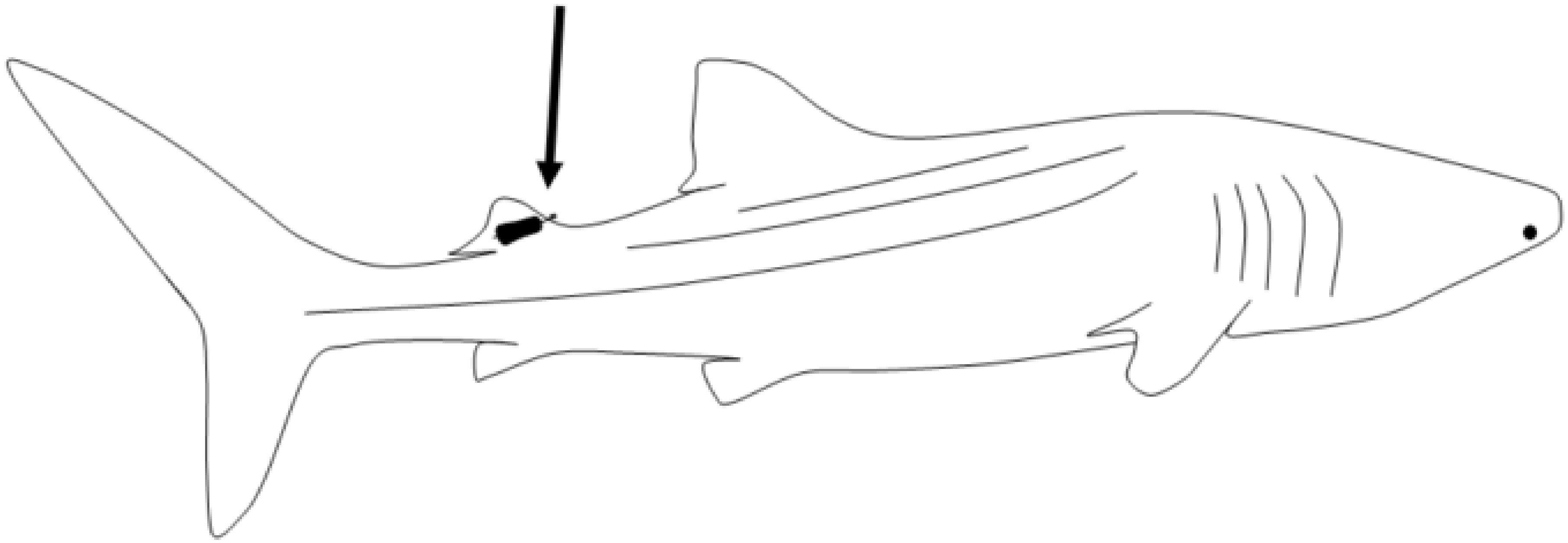

Figure 3

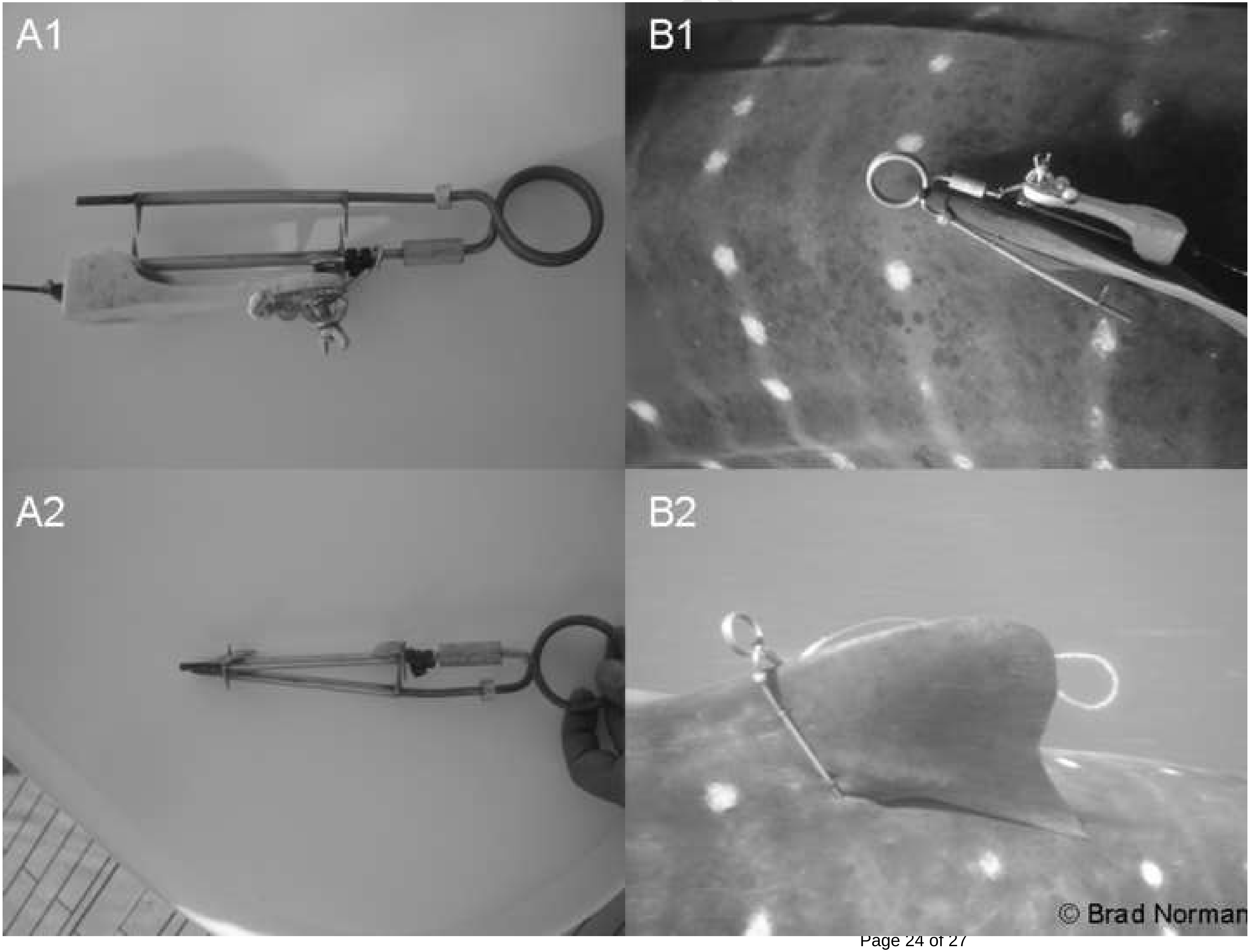

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Figure 4

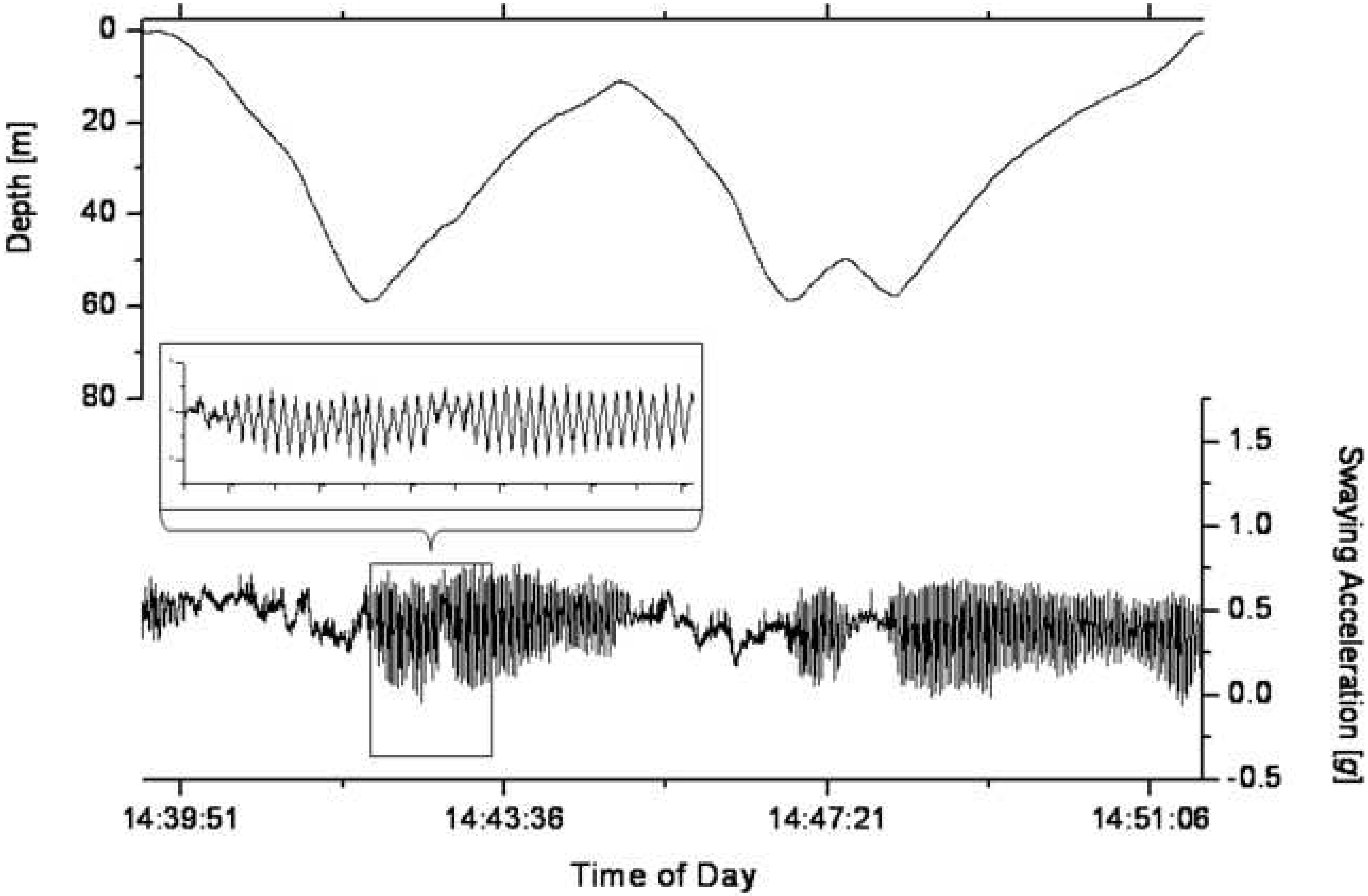
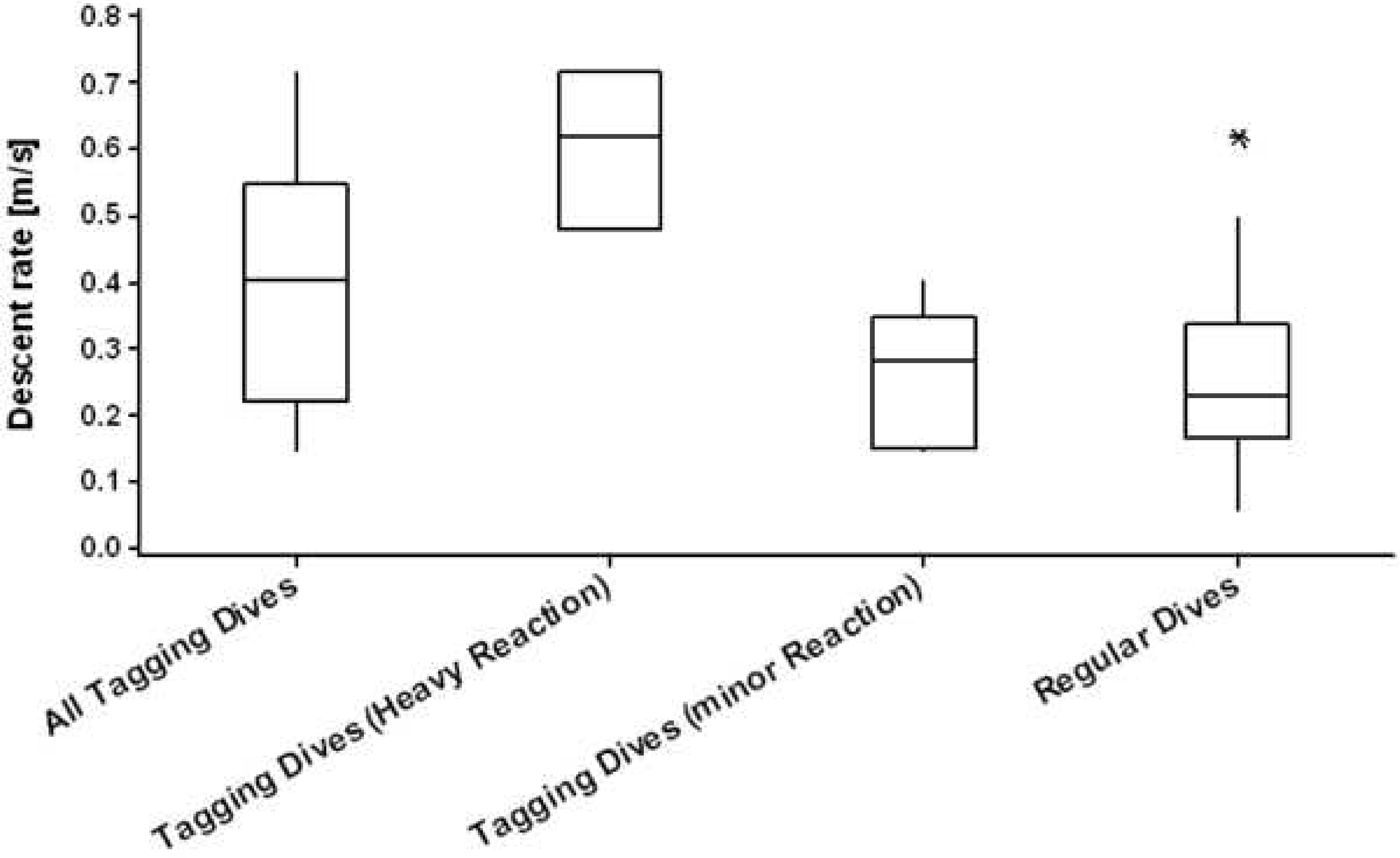

Depth [m]
0
20
40
60
80
Swaying Acceleration [g]
1.5
1.0
0.5
0.0
-0.5
14:39:51
14:43:36
14:47:21
14:51:06
Time of Day

Figure 5



Descent rate [m/s]
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
*
All Tagging Dives
Tagging Dives (Heavy Reaction)
Tagging Dives (minor Reaction)
Regular Dives

Figure 6