Animal Biotelemetry

METHODOLOGY

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Development and validation of a drill attachment for faster and safer deployments of fin-mounted geolocators in large-bodied sharks

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Abstract

Fin-mounted geolocators are widely used in marine studies to track animal movements and to design informed management strategies. However, the deployment protocols of such geolocators, which normally consist of drilling one to multiple holes using a template, can be challenging, and depending on the animal's stress physiology and ocean conditions, speed and accuracy may be crucial. Here, we present the plans for a drill attachment allowing the template-free drilling of up to four holes simultaneously for a faster, more accurate and safer deployment of fin-mounted geolocators. The drill attachment was successfully tested on four great and two scalloped hammerheads, *Sphyrna mokarran* and *Sphyrna lewini,* which were all tagged with 4-bolt Smart Position and Temperature (SPOT) tags. The time required to secure the geolocators, from drill alignment to the complete fastening of the last bolt, ranged from 68 to 85 s (78.2 ± 10.9 s, mean ± SD). The new drill attachment further allowed the successful tagging of a great hammerhead alongside a research vessel in rough seas that would have made the deployment using traditional protocols more challenging. Simultaneously drilling four holes reduces the need to keep the animal's fin steady for an extended period of time and thus makes the deployment of fin-mounted geolocators less dependent on the animal's behavior and the weather conditions. As such, the 4-hole drill attachment makes the mounting process faster and more reliable and should reduce the stress experienced by the animal.

Keywords: Satellite telemetry, New deployment method, Fin-mounted transmitter, SPOT tag, Animal movement, Multi-hole drill

Background

Understanding animal movements is crucial if we want to advance our knowledge about habitat use, niche partitioning and anthropogenic disturbances and to design conservation management measures (reviewed by [1]). Due to their ability to transmit data to orbiting satellites from which the data can be accessed directly, fin-mounted satellite-linked geolocators offer an option to remotely collect accurate horizontal movement data of animals that undergo long-distance migrations, such as large-bodied sharks (reviewed by [2]).

Despite a wide variety of forms, sizes, and fastening mechanisms available, mounting satellite-linked geolocators toward the tip of the shark's dorsal fin requires the shark to be caught and temporarily restrained for the drilling of one or more holes using a template for the positioning of the geolocator bolts [2]. However, the need to physically catch and restrain a shark inevitably elicits a physiological stress response [3], which can have detrimental impacts on the animal. One group

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of species that exemplifies these challenges during handling times are the hammerhead sharks (family *Sphyrnidae)* due to their low stress tolerance caused by a fast build-up of stress related metabolites [4]. Two of the more prominent species of this family are the great and scalloped hammerheads, *Sphyrna mokarran* and *Sphyrna lewini*. Over 90% of great and scalloped hammerheads had died before landing during a survey of the U.S. shark bottom longline fisheries [5]. In addition, great hammerheads were shown to have a 46% chance of dying up to 3 weeks after release, and their mortality was correlated with high lactate concentration after capture, i.e., a long fight time [4]. While the lethal concentration of lactate in other large sharks ranged between 16 and 20 mmol l^{-1} [6], great hammerheads were shown to reach this concentration in as little as 20 min fight time [4]. However, great and scalloped hammerheads are listed as *Critically Endangered* on the IUCN red list [7, 8] and both species would benefit from more fine-scale movement data, such as those generated by fin-mounted satellite-linked geolocators, allowing the discussion of more adequate conservation management measures [9]. To minimize the risks of detrimental effects during tagging activities, any sharks, but especially sharks with a fast lactate build-up and low stress tolerance, such as great and scalloped hammerheads, should, therefore, be brought to the boat and geolocators attached as fast as possible to reduce the probability of mortality [10].

The holding-in-place of a template and the subsequent drilling of individual holes through the shark fin is a critical and time-consuming process during the deployment of a fin-mounted satellite-linked geolocator. It additionally bears a high risk of complications if the template is moved before all holes are drilled, which is often unavoidable because of the animal's behavior, or the ocean surface conditions. Drilling all required holes at once would considerably reduce the overall time needed to complete the deployment protocol and would guarantee exact placement of the holes relative to each other. We, therefore, argue that a template-free deployment protocol that includes the simultaneous drilling of the needed number of holes is desirable to make the deployment protocols fast and less prone to complications.

Here we present a design for a drill attachment that allows drilling up to four holes simultaneously, with an effort equivalent to drilling only one hole, enabling a template-free deployment of a 4-bolt fin-mounted satellite-linked geolocator. We test the drill during deployments of 4-bolt fin-mounted satellite-linked geolocators on great and scalloped hammerheads and present the technical drawings of the drill attachment.

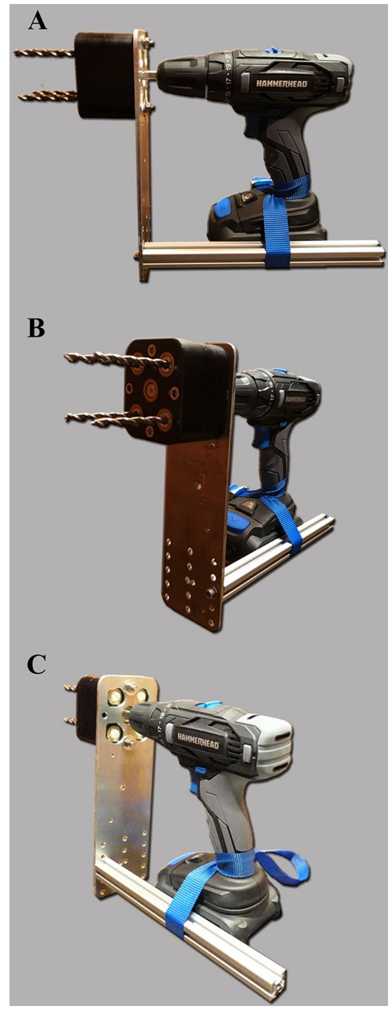

Fig. 1 Fully assembled drill attachment prototype fastened to a commercially 20V cordless 2-speed drill driver. **A** Left lateral, **B** anterior, and **C** posterior view of the setup used in this study. The drill attachment is connected to the drill driver via the center drive shaft fastened within the drill driver head and the gear box is kept from rotating via the bar secured to the battery of the drill driver using a nylon strap. By removing the two drill bits on either the left or right side of the attachment, one can also use the drill attachment to drill two holes simultaneously for the deployment of the SPOT-380 tag, which shares the same vertical spacing between the bolts as the SPOT-364 tag. The figure shows the prototype of the drill attachment used for the in-field validation. The details of the refined attachment are shown in the Technical Drawings in the Additional file 1

Materials and methods

Drill attachment design and dimensions

Our newly designed drill attachment consists of a gear box containing the mechanism to convey the rotation of the drill driver head on four individual drill bits, a multi-hole backplate, i.e., an attachment arm, and a horizontal bar that fixes the backplate to the base of the drill driver

(Fig. 1). The drill attachment was designed based on the dimensions of a frequently used fin-mounted satellite-linked geolocator type, namely, the Smart Position and Temperature (SPOT, Wildlife Computers, Redmond, WA, USA) tag with four removable urethane bolts used to attach the tag to the fin. The chosen tag model was a SPOT-364[1] tag and the exact dimensions of the tag including the location and spacings between the four bolts were taken from technical drawings provided by the manufacturer, i.e., the drilling template. The prototype of the full drill driver setup with the fastened drill attachment used for the in-field validation is shown in Fig. 1 and the build is described below. During the in-field validation we used a prototype with a non-specific multi-hole aluminum plate as an attachment arm and a square bar (Fig. 1) as a connection between drill attachment and drill driver base, which is necessary to keep the gear box from rotating when drilling. After the successful in-field validation we further refined these two items by designing a specific attachment arm that holds the gear box and creates a more user-friendly version compared to the prototype. Technical drawings of the main parts including the refined gear box and multi-hole plate, i.e., attachment arm, are shown in Figs. 2, 3, 4, 5, and 6. Figures 2, 3, 4, 5, 6 have been scaled for presentation purposes. For re-building purposes, the original technical drawings should be used. All original technical drawings are accessible in the Additional file 1 to this manuscript. The side of the drill attachment facing away from the drill driver will hereafter be referred to as the anterior side, whereas the side facing toward the drill driver the posterior side.

The center piece of the drill attachment is the gear box ($79 \times 70 \times 52$ mm) consisting of two halves made from aluminum (EN AW-6082/anodized) that are secured together by four stainless-steel bolts situated within the middle at the top, bottom, the left and right side of the gear box (Fig. 2). To fasten the bolts, the posterior half of gear the box contains four inserted threads (M6). The threads are aligned by four center bushings (see Technical Drawing C in the Additional file 1). In the prototype the bolts on the left and right side were shorter (40 mm), whereas the bolts at the top and bottom of the gear box were longer (60 mm) and protruded the box by 16 mm so they could be used to attach the gear box to the non-specific multi-hole plate (Fig. 1). The refined version of the gear box has a circular extension at the posterior end facing the driver head (see Technical Drawing A in the Additional file 1) that fits into the circular opening of the refined attachment arm (see Technical Drawing P in the Additional file 1). This allows the refined gear box to be secured into the circular opening of the refined attachment arm by fastening a bolt at the top of the circular opening (see Technical Drawing R in the Additional file 1). With this refined setup, bolts of different lengths are no more needed, and four 40 mm bolts can be used to secure the two gear box halves together. We included these refinements to make the attachment and potential replacement of the gear box easier and faster. Furthermore, the refined setup allows to fasten the gear box at different angles relative to the drill driver head based on the user's preference.

The center drive shaft (Fig. 3A), which exits the gear box on the posterior side and passes through the opening of the attachment arm, is secured within the head of the drill driver. Within the gear box, the center drive shaft connects to a centered gear wheel (nr. teeth: 20, tooth module: 1.5 mm, working depth: 16 mm, Fig. 4A) via a pressfit (h6/P7, Fig. 3B). The centered gear wheel engages with 4 peripheral, smaller gear wheels located in the corners of the gear box (Fig. 5). Two of the peripheral gear wheels have 16 teeth (tooth module: 1.5 mm, working depth: 16 mm, Fig. 4B), while the other two are characterized by 15 teeth (tooth module: 1.5 mm, working depth: 16 mm, Fig. 4C). The different sized peripheral gear wheels allowed us to position the center of the peripheral gear wheels, i.e., where the drill bits are located, at the corners of a rectangle 41 mm apart vertically and 34 mm apart horizontally. These distances between the rotating drill bits mimic the urethane bolt spacings of the SPOT-364 tag. The different tooth numbers of the peripheral gear wheels result in a slight, about 8%, difference in rotational speed of the drill bits.

Each peripheral gear wheel is attached to a gear shaft (Fig. 6A) using a pressfit (h6/P7) and each gear shaft holds a brad-point drill bit that is secured within the gear shaft (Fig. 6 B) using two maggot screws ($M6 \times 8$ mm) on opposite sides of the base of the shaft. The base of each drill bit has two mill-cut surfaces on either side to offer a point of contact for the maggot screws within the gear shaft (Fig. 6C). Based on the diameter of the urethane bolts, we chose 6.5 mm brad-point drill bits (length: 100 mm, Fig. 6C) made from high-speed cutting steel (HSS). The brad-point ending allows users to easily align the drill bits to the fin and creates a clean exit of the hole on the other side. We chose HSS drill bits due to this material's high wear resistance allowing to re-use the drill bits without risking dullness. The drill bits exit the gear box on the opposite side compared to the center drive shaft, i.e., the anterior side of the gear box. The four drill bits are perfectly parallel to each other, which will result in perfectly parallel holes as well, making the passing of the bolts through the fin and fastening the screws easier.

[1] https://static.wildlifecomputers.com/SPOT-Finmount-Shark-Suite.pdf, last accessed March 15th, 2022.

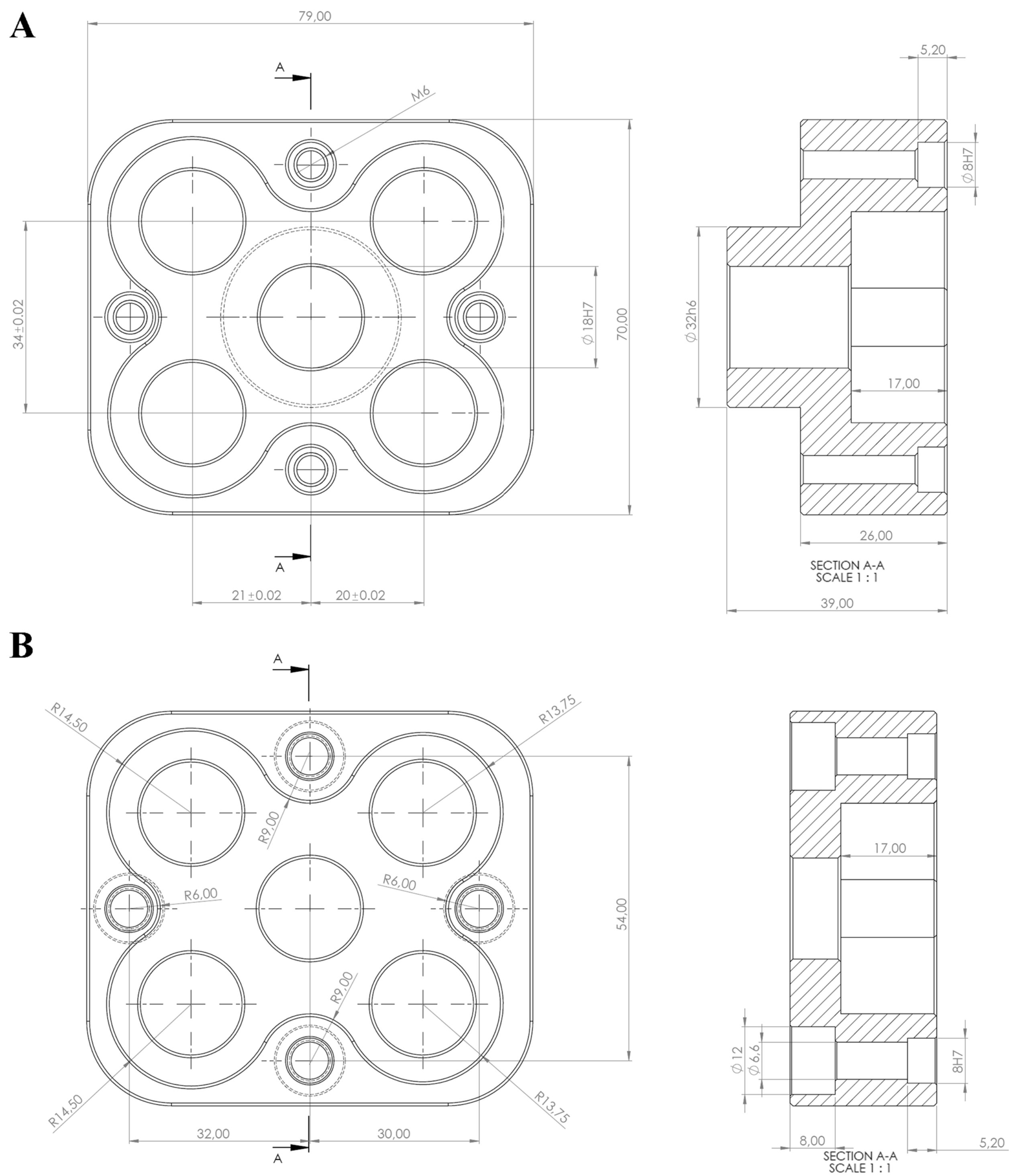

Fig. 2 Gear box. Technical drawings of the **A** posterior and **B** anterior halves of the gear box. "A —▸|" designates the sectional plane of the cross sections that are shown on the right side of the figure. All measurements are in millimeters. 18H7, 32h6 and 8H7 represent tolerance levels of the components. Technical drawings of the gear box halves with the bronze bearings can be found in the Additional file 1

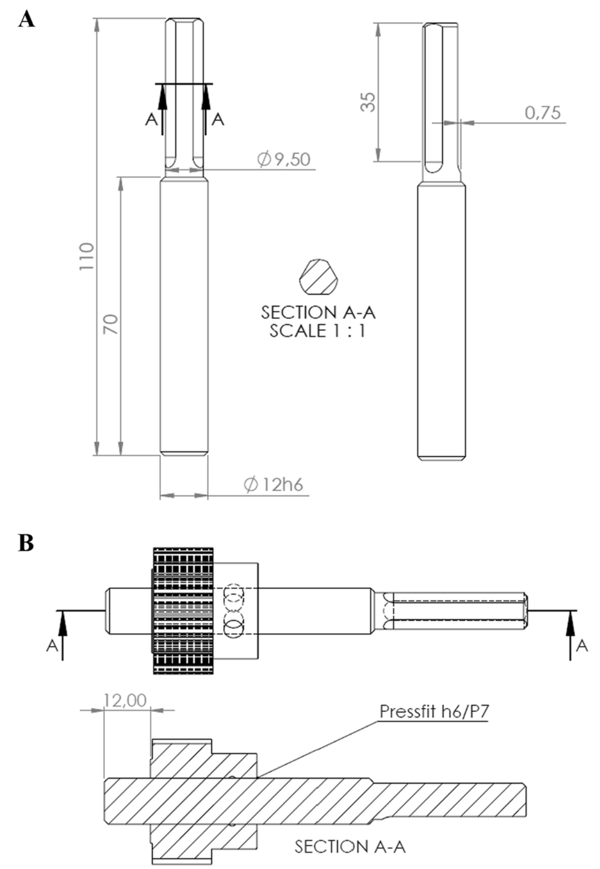

Fig. 3 Center drive shaft. Dimensions and cross sections of **A** center drive shaft as well as **B** center drive shaft with fitted 20 teeth center gear wheel. "A ─►|" designates the sectional plane of the cross sections. All measurements are in millimeters. 12h6 represents tolerance levels of the components. h6/P7 provides the details of the pressfit and tolerance levels of its components and their interference

All contact surfaces between drive shafts and the gear box are lined with bronze bearings (see Technical Drawings D and E in the Additional file 1). The posterior opening of each gear drive shaft is closed with a short plastic bolt that can be fastened into the opening (Fig. 1C).

The multi-hole plate, i.e., the attachment arm, allows the attachment of a bar at the base of the arm (see Technical Drawings Q and R in the Additional file 1) using a bolt that passes through the arm and is secured into the bar. The bar is used to connect the drill attachment and the attachment arm to either side or underneath the drill driver handle or the battery. Here, we used a small nylon strap to secure the bar to the left side of the battery (Fig. 1). An array of available holes in the attachment arm allows users to individually place the bar based on the dimensions and design of the used drill driver. This makes the drill attachment compatible with diverse drill drivers.

Due to the design being built around a center gear wheel engaging with peripheral gear wheels, the drill driver has to be set to spin counterclockwise, i.e., in reverse, for a forward rotation of the drill bits during drilling. The drill attachment can be completely taken apart to allow for maintenance, cleaning, and replacement of parts. The technical drawing of the fully assembled drill attachment is shown in Technical Drawing R in the Additional file 1.

In-field validation

To validate the new drill attachment and test its feasibility for the use in a marine environment, we used the drill attachment during the work for an ongoing project (Heim et al., unpublished data), where great and scalloped hammerheads are tagged with fin-mounted SPOT-364 tags. The new drill attachment was fastened to a commercially available 20V 2-Speed cordless drill driver (Fig. 1). The fully assembled gear box weighed 1.15 kg. A photographic time series of a SPOT-364 tag deployment during the in-field validation of the new drill attachment is shown in Fig. 7.

The sharks were caught in the Florida Keys (N 24° 40′ 1″, W 81° 32′ 39″, USA) using bottom-set longlines or a polyball-float fishing technique as described by Guttridge et al. [11]. One longline set consisted of two separate lines with each line containing 50 16/0 non-offset circle hooks and a soak time of 60 min for each line. Since no hook timers were used, we were not able to control for how long a shark was hooked before the longline was hauled. Therefore, upon capture of a hammerhead on a longline, the state of the shark was visually assessed and, if the shark was designated as a tag candidate, the shark was brought onto a small swimming platform at the back of the boat. During polyball-float fishing protocols of the corresponding project (Heim et al., unpublished data) only a maximum of two separate floats are deployed at the same time, so that we were able to monitor both and visually confirm if a shark bit the hook based on the float movement. This allowed us to start a timer as soon as the shark was hooked. Once a shark was hooked, the float was retrieved and the shark brought to the boat using hand-lining techniques. A time-limit from bite-to-release of 12 min based on lactate build-up levels described by Gallagher et al. [4] was strictly adhered to. If the time limit was reached, a shark would have been released no later than 12 min after it initially bit the hook independently if the SPOT-tag would have been deployed or not. The vessel used during the polyball-float fishing technique did not have a swimming platform, so that hammerheads caught via polyball-float fishing technique were

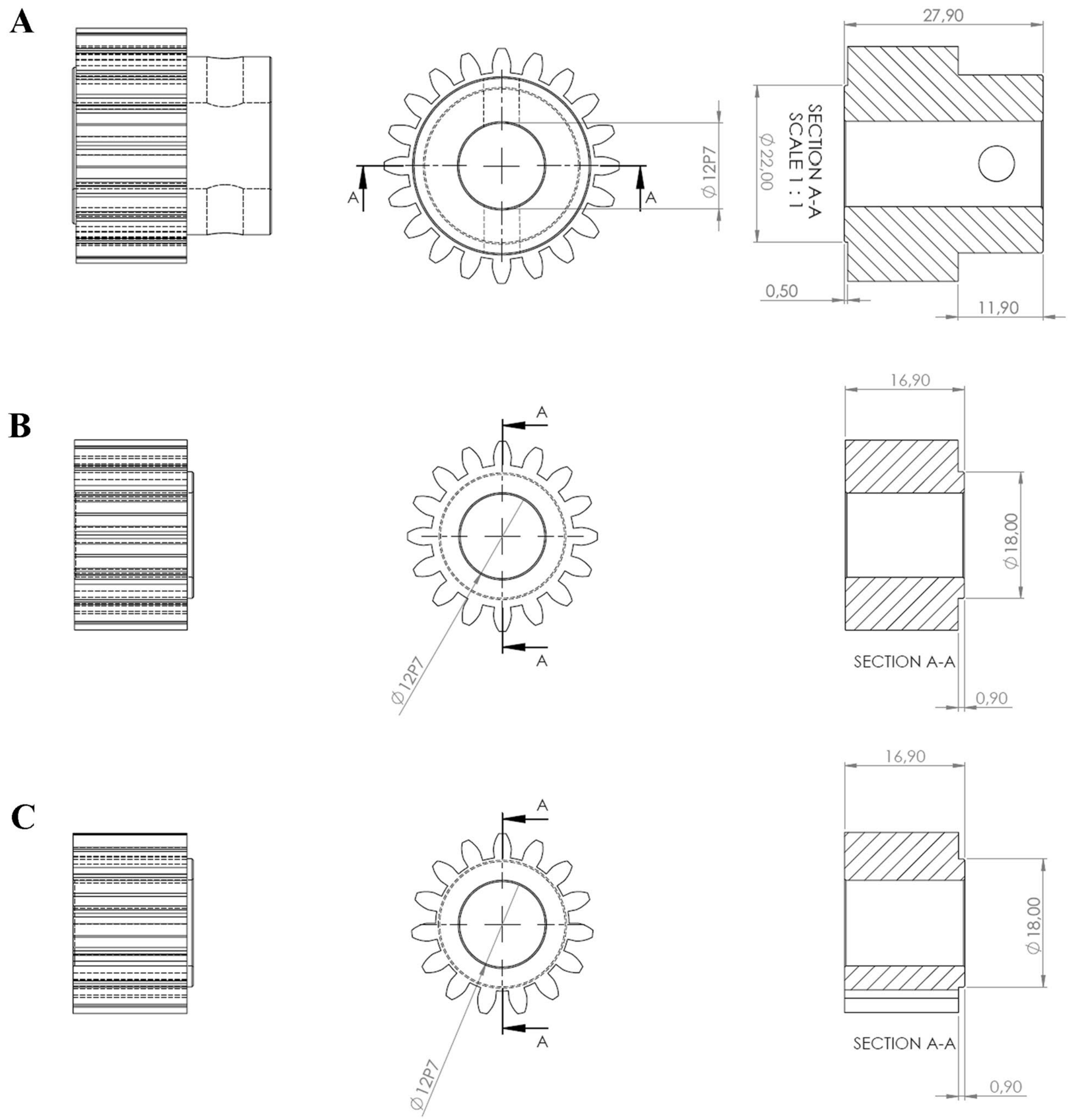

Fig. 4 Center and peripheral gear wheels. The lateral, top and cross-sectional views of **A** centered gear wheel with 20 teeth, **B** larger peripheral gear wheel with 16 teeth and **C** smaller peripheral gear wheel with 15 teeth are shown from left to right. All gear wheels have a tooth module of 1.5 mm. "A ⟶" designates the sectional plane of the cross sections that are shown on the right side of the figure. All measurements are in millimeters. 12P7 represents tolerance levels of the components

brought alongside the vessel, with the leader secured to the bow of the boat and a tail-rope, which was put around the pre-caudal area of the shark, secured to the stern of the boat. Independently of the capture method, each shark was sexed (based on the presence or absence of claspers), measured (pre-caudal [PCL], fork [FL] and stretched total length [sTL] in cm) and tagged with a SPOT-tag and an external National Marine Fishery Services dart-tag before it was released.

The deployed SPOT-tags consist of an epoxy case and four pre-made holes accommodating four hollow urethane bolts. The transmitters were painted with

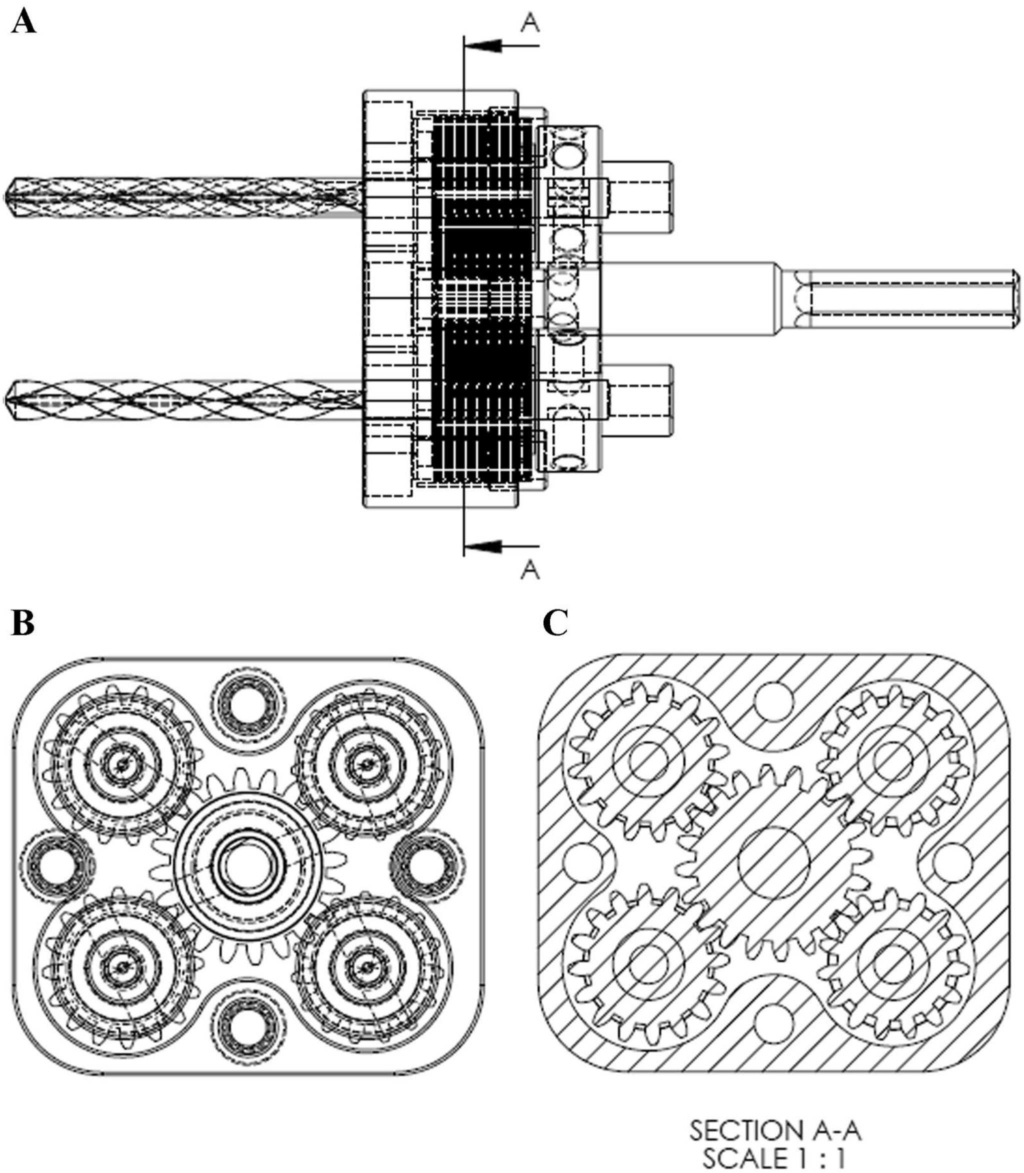

Fig. 5 Anterior half of the gear box with center drive shaft, gear wheels and drill bits. **A** Lateral view of the anterior half of the assembled gear box. **B** Top view of the anterior half of the gear wheel with bronze bearings and gear wheels. **C** Cross section of the anterior half of the gear box with gear wheels. "A ⟶|" designates the sectional plane of the cross section. All measurements are in millimeters

anti-biofouling paint (Micron 66® by Interlux or Propspeed® Clear Coat), and the urethane bolts were glued into the premade holes of the tag case pre-deployment to save additional time during the deployment protocol. All tags were initiated on land no more than 4 days before deployment to test the location accuracy.

The tags were placed as high as possible based on fin size and tag weight toward the leading edge of the first dorsal fin of the shark (Fig. 7). Once the holes were drilled (Fig. 7A–D), the urethane bolts were pushed through the holes in the fin tissue (Fig. 7E, F). End-cutting pliers were used to cut two of the four protruding urethane bolts flush with the fin surface. Next, the cut urethane bolts were secured by fastening a combination of a rubber washer, stainless steel washer and stainless steel screw into the hollow part of each of the cut bolts using the modified urethane-covered screwdriver bits provided by the manufacturer. Upon securing the first two urethane bolts, the two remaining urethane bolts were cut flush and secured as described above.

To record the duration of the SPOT-tag deployment procedure, a GoPro camera was mounted either

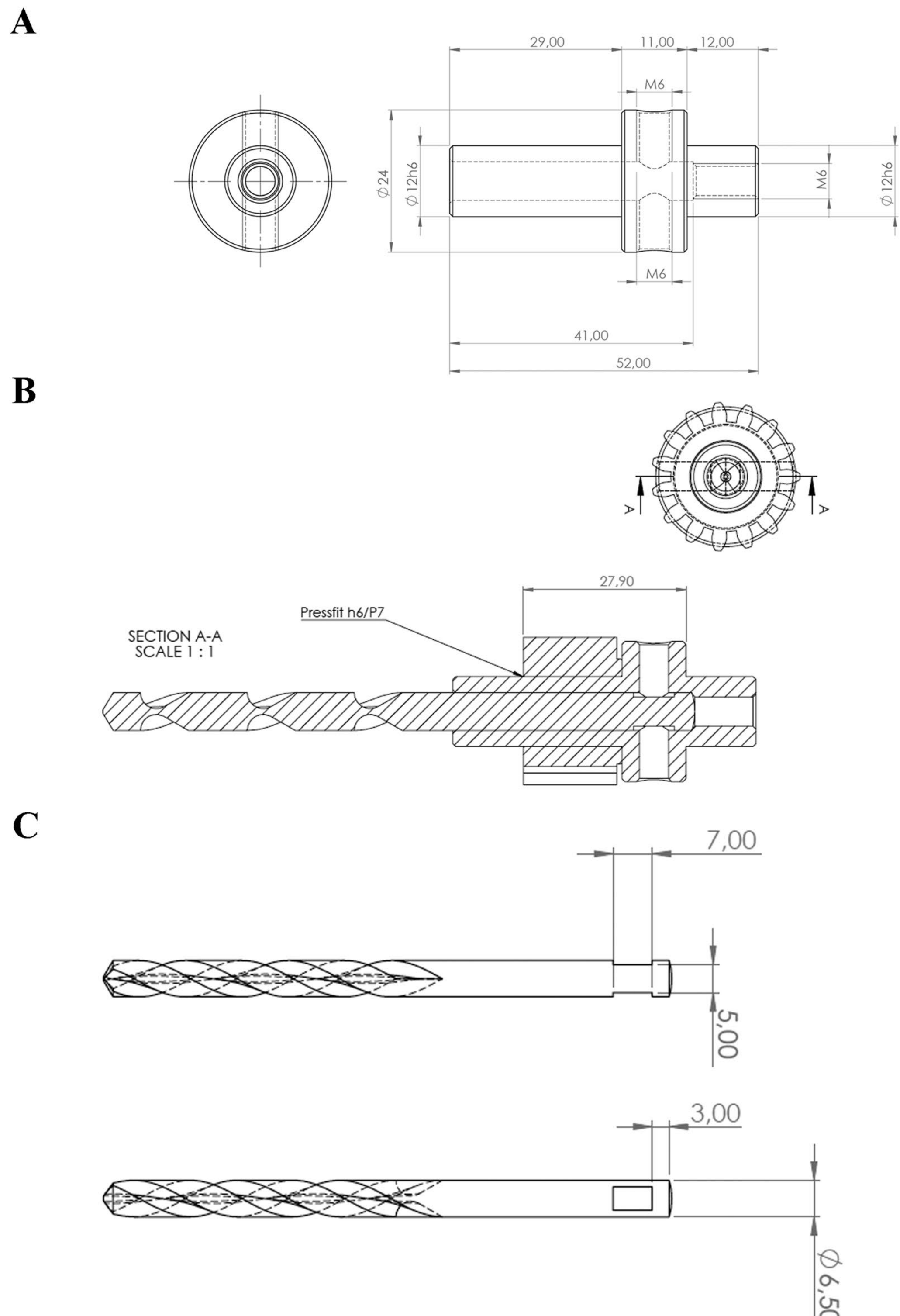

Fig. 6 Drill gear shaft and drill bits. **A** Lateral view of the drill gear shaft within which the drill bits are fixed and **B** cross section of the drive shaft with a mounted drill bit and the affixed smaller 15 teeth gear wheel. **C** Dimensions of the drill bits and the mill-cut contact surfaces for the maggot screws. "A ⟶|" designates the sectional plane of the cross section. 12h6 represents tolerance levels the components. h6/P7 provides the details of the pressfit and tolerance levels of its components and their interference. All measurements are in millimeters

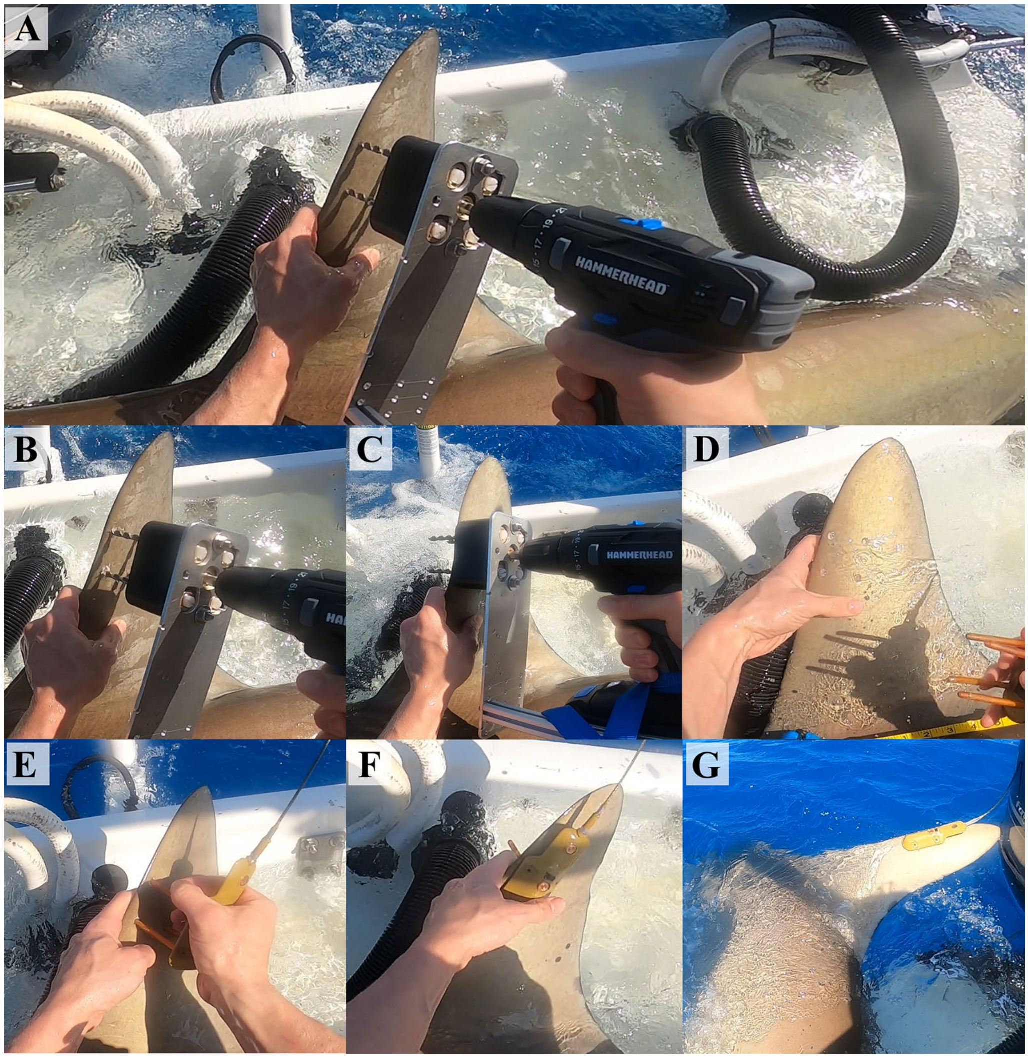

Fig. 7 Photographic time series of the deployment of a SPOT-364 tag on shark 5. The time series shows the **A** alignment of the drill attachment, **B** engagement of the drill, **C** completion of the drilling procedure, **D** the four simultaneously drilled holes, **E** alignment of the SPOT-364 tag bolts with the holes, **F** placement of the SPOT-364 tag before the fastening of the bolts (not shown), and **G** complete release of shark 5 after 108 s with the SPOT-364 tag tightly fastened toward the top of the first dorsal fin

to the first author's chest and/or head or the frame of the boat's center console. Based on the recorded video material, four timepoints were noted and the time between them calculated. For sharks tagged aboard the research vessel, the timepoints recorded were when the shark was first brought on the boat (1), when the drill bits of the drill attachment were aligned with the location, where the SPOT-tag was going to be placed (2), the complete fastening of the last bolt (3) and the complete release of the animal (4). Here, we report the time duration between timepoints 2 and 3, as well as between timepoints 1 and 4 in seconds. Sharks tagged onboard the vessel were caught via longlines, i.e., for these sharks we were not able to record how long they have been hooked before retrieval of the line. For the shark tagged alongside the vessel, we recorded the time from when the shark initially bit the hook, which we were able to visually confirm by the polyball-float movement and clear water conditions, until the complete release of the shark. However, timepoints 1–4 were not available for the polyball-float fishing capture. Unfortunately, recorded timepoints of previous SPOT-364 tag deployments without the new drill attachment were not available. We also could not find comparable values from other shark tagging studies in the published literature. We, therefore, cannot compare the

Table 1 Metadata of tagged sharks and time intervals for geolocator deployments

Shark-ID #	Species	Sex	sTL *[cm]*	Gear	Handling duration *[seconds]*	Tagging duration *[seconds]*	Tagging date *[dd-mm-yyyy]*	Days at liberty
1‡	*S. mokarran*	F	223	LL	105	68	01.02.2022	114
2‡	*S. mokarran*	M	227	LL	93	83	04.02.2022	78
3	*S. mokarran*	M	277	LL	79	71	04.04.2022	n.d
4‡	*S. lewini*	F	200	LL	81	74	04.04.2022	51
5	*S. lewini*	F	284	LL	108	85	04.04.2022	93
6	*S. mokarran*	M	337	PBF	630	NA	11.04.2022	178*

In column 1 ‡ indicates immature sharks. LL stands for sharks that were caught using bottom set-longlines and PBS for the great hammerhead that was caught using a polyball-float fishing technique. For sharks caught using longlines, the time periods in the column "handling duration" show the time in seconds from when the shark was first brought onto the boat until full release, whereas it shows the time from bite-to-release for the shark that was caught using a polyball-float fishing technique (shark 6). The sex of each shark in column 3 is abbreviated as F for female and M for male sharks. The days at liberty were calculated as the difference in days between the tagging date and the date of the last location transmission with the last day being included in the calculation. Shark 3 did not report any data post-release. *The geolocator of shark 6 was still active by the time this manuscript was accepted with shark 6 generating location data daily. Units and data formats are displayed in in italic font within [].

recorded times with the new drill attachment to other geolocator deployments.

Results

We aimed to build a new drill attachment that allows the template-free drilling of 4 holes simultaneously to make the deployment of fin-mounted satellite-linked geolocators for marine animal tracking studies faster and safer. We tested this new device on a total of 6 hammerheads that were caught and successfully tagged with SPOT-364 tags (Table 1). Four were great hammerheads (1 female, 3 males) and two were female scalloped hammerheads. The great hammerheads measured between 223 and 337 cm sTL and two individuals were sexually immature. The female scalloped hammerheads measured 200 and 284 cm sTL, with the smaller shark being sexually immature.

All sharks except shark 6 (see Table 1) were caught via bottom-set longlines and tagged on the back of the boat. For these sharks, the time span it took from first bringing the sharks on the boat to complete release, i.e., the handling duration, was 93.2 ± 13.31 s (mean ± SD, range: 79–108 s, Table 1). On average it took 78.2 ± 10.9 s (mean ± SD, range 68–85 s, Table 1) to fully mount a SPOT-364 tag to the first dorsal fin of a hammerhead shark. Shark 6 was tagged alongside the research vessel, and we only recorded the time from when the shark bit the hook to full release which was 10.5 min (630 s). Shark 6 was tagged in approximately 300 ft of water with 5 ft waves at a short interval of approximately 5 s (pers. communication, John Buckheim, commercial fisherman and boat captain during the polyball-float fishing activities). These challenging conditions made the time needed to bring the shark alongside the vessel, to secure the shark and to deploy the SPOT-364 tag longer than during calm weather conditions (pers. observation, V. Heim). However, despite the challenging conditions, aligning the drill and drilling all four holes using the newly developed drill attachment was a matter of 2 s.

In all sharks, independently of capture method or whether the shark was brought onto the vessel or tagged alongside it, the drill successfully drilled 4 complete holes simultaneously through the fin tissue in one swift movement. No further drilling, enlarging, or adjusting of the holes after the initial drill movement was necessary so that the bolts of the tags could be pushed through the fin directly after drilling. In addition, all four holes were drilled perfectly parallel to each other due to the positioning of the drill bits within the drill attachment. During the deployment of the tag on shark 2 (see Table 1), one of the drill bits broke just after establishing contact with the fin, so that the fourth hole had to be drilled separately, making the deployment process longer. All sharks were evaluated to be in good condition upon release based on the sharks starting to beat their caudal fin immediately and swimming of in a stable upright swimming position. All sharks but one (shark 3) generated data post-release and were tracked, i.e., days at liberty, between 51 and 178 days, with shark 6 still generating daily data at the time of submission of this manuscript (Table 1).

Discussion

Here, we present a new drill attachment that allows the simultaneous drilling of four holes for an improved deployment protocol for 4-bolt fin-mounted satellite-linked geolocators. Furthermore, we present the results from the in-field validation of the drill attachment during the tagging of great and scalloped hammerheads. The new drill attachment allowed accurate, fast, and safe geolocator deployments, making the use of a drill template redundant. This new drill attachment has a high potential for use during tracking studies in the marine environment as it improves the deployment protocol compared to using a single bit drill driver.

Drill attachment design and in-field validation

Using the drill attachment, we were able to fasten fin-mounted SPOT-364 tags consistently in under 90 s (measured from when the drill attachment was aligned with the fin to complete fastening of the transmitters) when sharks were brought onto the research vessel. The template-free drilling of four holes using our new drill attachment was a matter of 1–2 s, independently of the sharks' behavior, the ocean conditions, or the capture method, and is approximately equivalent for the time needed to drill a single hole otherwise. The slightly different rotational speed of the differently sized peripheral gear wheels did not impact the drilling process. Apart from certainly being much faster compared to drilling the four holes independently through a template, the accuracy of the holes was much higher using the new drill attachment. If the holes are drilled independently there is the potential that the individual holes are drilled at a different angle. Non-parallel holes can cause the bolts to protrude on the other side of the fin at different angles, which makes it more difficult to fasten the screws. Our drill attachment design produces perfectly parallel holes, something that cannot be guaranteed when using a single drill bit.

In addition, one of the major advantages of the new drill attachment is that a drill template is no longer needed. Drill templates are used to drill the holes for the urethane bolts in the correct location, but their position may be shifted even in calm seas and especially if the shark moves or if waves move the boat. Should one have to re-align the drill template after having drilled some but not all holes, the handling time of the shark will increase. We tested the drill on hammerhead sharks that were small enough to be brought on a small swimming platform at the end of the research vessel, providing a relatively stable situation during tag deployment despite the rough weather. However, we also successfully tested the drill attachment during the deployment of a SPOT-364 tag offshore on a great hammerhead shark that was brought alongside the research vessel in 5 ft seas. While we cannot compare the time it took to deploy geolocators between sharks tagged on vs. alongside the vessel, the template-free drilling was equivalently swift and precise independently of the fishing method. The ability to safely drill four holes in the correct location without a template to accommodate the geolocator bolts, should also allow scientists to tag sharks in rougher seas, even when the shark cannot be brought onto a stable platform.

We acknowledge that not having timepoints from previous SPOT-364 tag deployments without the drill attachment and the lack of comparable timepoints from other shark tagging studies in the published literature keeps us from delivering numerical proof of faster SPOT-364 tag deployments. However, we suggest that the template-free drilling of four holes simultaneously will always be faster than drilling four holes individually through a template using a single drill bit. Based on the in-field validation, we estimate that the drilling time with our new drill attachment is equivalent to the time it takes to drill one hole. As such, we suggest that the time it takes to drill the 4 holes with the new attachment is approximately a quarter of the time it would take to drill the 4 holes individually. We not only drill all holes simultaneously, but the alignment of the drill is only required once as well and there is no more need for the repeated forward–backward movement nor the aiming of the drill bit for the holes in the drill template. Together with the described advantages in precision and shark safety, we believe that the drill attachment provides an improvement in the deployment of fin-mounted geolocators.

Further considerations

The sharks tagged during the in-field validation are part of an ongoing study (Heim et al., unpublished data). Due to the hammerhead shark's high sensitivity to stress, fast lactate build-up rates and correspondingly high mortality rates when caught [4, 5, 12], the use of a 4-bolt geolocator necessitating drilling and fastening four bolts poses a high a risk to the sharks' health. With our new drill attachment, we were able to not only reduce the duration of the deployment protocol of the 4-bolt SPOT-364 tag to times comparable with the previously used 2-bolt SPOT-380 tag (pers. observation, Heim V.), which should reduce the amount of stress the sharks experience, but it also enabled us to use a geolocator with a longer battery life. The drill attachment, therefore, can support the use of geolocators generating data sets that span longer time periods, which can be crucial when it comes to designing efficient conservation measures [13, 14].

All shark but one (shark 3, Table 1) started transmitting data shortly after release and we recorded tracking durations of 51–178 days (Table 1) with the geolocator of the shark with the longest tracking duration still generating data daily. Great hammerheads can die from the experienced stress during the capture up top 3 week post-release [4]. We used geolocators with an estimated battery life of approximately 300 days. There can be various reasons for the early cessation of transmissions in shark 1, 2, 4 and 5 (e.g., geolocator malfunction, fishing pressure). Given the recorded days at liberty, we are confident that the reason is not tied to the capture or handling duration of the sharks, highlighting the potential of our drill attachment to save time during the geolocator deployments. It must be noted that out of the six sharks, the shark with the shortest handling and tagging duration (shark 3, Table 1), did not report after release, despite swimming off in a stable, upright position and with a steady caudal fin movement. While the fate of the shark cannot be determined conclusively [15], it is a possibility that this shark died post-release. This shows why it is crucial to develop tagging protocols that are as fast as possible, to further minimize the associated risks for the sharks.

Our drill attachment was designed to be fully deconstructed. This allows access to every part used in the drill attachment. Despite most parts being made of stainless steel, we recommend that the drill attachment be disassembled at the end of the day if it was exposed to sea water, that all parts be cleaned with fresh water and moving parts treated with a lubricant to ensure proper function during following deployments. The weight of the fully assembled gear box is only 1.15 kg and the whole drill setup can, therefore, be operated comfortably with one hand.

During the deployment of the transmitter on shark 2, the bottom left drill bit broke. This was most likely related to improper handling. Prior to this deployment, the drill was kept loosely in a box on the moving boat, in which the bits might have been hitting the inside of the box when the boat was hit by waves. For the next four deployments, a padded sleeve built from a hard-plastic pipe that fit over the drill attachment was used to protect the drill between deployments, and we did not have any further complications during deployments. Should a drill bit break during the deployment process, e.g., if the drill is dropped, replacing a drill bit takes time and requires appropriate tools to remove and disassemble the gear box. Replacing a drill bit, while a shark is secured is, therefore, not feasible and this is a limitation of our drill attachment. However, with the new and refined gear box and attachment arm (see Technical Drawings A and P in the Additional file 1), changing a fully assembled gear box only requires the loosening and re-fastening of the drill driver head and one screw at the top of the attachment arm. As such, changing the assembled gear box is fast. In conclusion, we recommend storing the drill on the boat in a way that keeps the bits safe from being hit against another object to avoid complications during the deployment of the geolocators. However, keeping a second fully assembled gear box on the boat offers a further precautionary measure in case of a broken drill bit.

Nowadays, there is a variety of satellite-linked geolocators in different sizes, designs and with various attachment methods from different manufactures, allowing scientists to choose the best suited geolocator for their study species and research questions. Our drill attachment was designed based on a specific fin-mounted satellite-linked geolocator type containing 4-bolts, namely, the SPOT-364 tag by Wildlife Computers. This specificity limits the usage of our drill attachment. However, the modularity of the drill attachment and the possibility to individually remove drill bits, make it possible to mount one to four drill bits individually. Because the 4-bolt SPOT-364 tags and the 2-bolt SPOT-380 tags from Wildlife Computers have nearly the same vertical spacing between the bolts (SPOT-364: 41 mm, SPOT-380: 40 mm), the drill attachment can be modified to simultaneously drill two holes by removing two vertical drill bits (see Fig. 1 for reference), allowing a faster and safer deployment of SPOT-380 tags as well (Fig. 1). For studies using geolocators that differ significantly in the spacings between the bolts or have a different number of bolts, a different attachment would need to be built.

During the design process of the presented drill attachment, the most critical aspect was to find a combination of gear wheel sizes and tooth counts that allowed the drill bits to be aligned with the bolt locations on the geolocator. Our final design employs a center drive shaft with a centered gear wheel that engages with peripheral gear wheels tightly fitted within a case, and we think this concept can serve as a base to design similar drill attachments for other geolocator types with different dimensions or different number of bolts, or geolocators from different manufactures as well. We refer scientists that want to build a similar drill attachment to the original technical drawings in the Additional file 1. The technical drawings contain all the necessary information and detail that the individual parts of the drill attachment can be manufactured in an engineering workshop, where tools for pressing, cutting and milling are available. Scientists that want to build a similar drill attachment but for a different geolocator, should contact the manufacturer regarding the geolocator dimensions and the spacing between the bolts. This information will be needed to find a gear wheel combination that accommodates the spacing between the bolts.

We hope that the presented drill attachment and the feasibility to build multi-hole drills for faster geolocator deployments motivate manufacturers to keep potential gear wheel sizes and corresponding achievable spacings between bolts in mind when they are designing new geolocators. As scientists we have a responsibility to explore any options available to make these deployments as fast and as safe for the animal as possible.

Conclusions

The goal of this study was to design a drill attachment that allows faster and more accurate fin-mounted satellite-linked geolocator deployment. Our motivation was based on the high stress sensitivity of hammerhead sharks, making speed during deployments a crucial factor. Any geolocator deployment comes with inherent risks for the animal's wellbeing, and deployment protocols with the smallest risks should be developed [16]. Therefore, from an ethical standpoint, a reduced handling time of the study animal, which was shown to increase the release condition and subsequent survival of on-board tagged blacknose sharks, *Carcharhinus acronotus* [10], is desirable independently of the species, and the least stressful deployment protocol must be chosen. We hope that our drill attachment can be used by other scientists and that it encourages the development of drill attachments for other type of geolocators as well.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s40317-022-00304-z.

Additional file 1. Technical drawings.

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Author contributions

VH, DL, JH and DE conceived the idea of the new drill attachment and gave crucial inputs for the final design; DL designed the technical drawings and built the drill attachment; VH conducted the in-field validation of the drill attachment and led the writing of the manuscript. All authors reviewed the manuscript drafts. All authors read and approved the final manuscript.

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Availability of data and materials

The original technical drawings of the drill attachment are openly available in the Additional file 1. Videos of the in-field validation of the drill from which the time intervals of the geolocator deployments were extracted are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate

All tagging of great and scalloped hammerhead sharks in the Florida State waters of Martin, Monroe and Palm Beach Counties and the Florida Keys National Marine Sanctuary was approved and conducted under the following permits: FKNMS-2021-066 and SAL-21-1345-SRP (issued to Dr. R. Dean Grubbs) and SAL-21-2333B-SRP (issued to Dr. Tristan L. Guttridge, Dr. Bryan Keller, Dr. Mark Bond, Dr. Philip Matich and Vital Heim).

Consent for publication

Not applicable.

Competing interests

All authors of this manuscript declare that there are no competing interests.

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