The slippery head of the fastest fish

The swordfish (Xiphias gladius) is reputedly the fastest swimmer on Earth. Its concave head and iconic sword are unique characteristics, but how they contribute to its speed is still unknown. Our paper reports the discovery of a complex organ in the head. It consists of an oil-producing gland, which is connected to capillaries that communicate with oil-excreting pores surrounded by denticles. The oil is distributed from the pores over the front part of the head. The oil inside the gland is identical to that found on the skin and is a mixture of methyl esters commonly found in plants and animals. We hypothesize that the oil layer, in combination with the denticles, creates a hydrophobic layer that reduces streamwise friction drag and increases swimming efficiency.

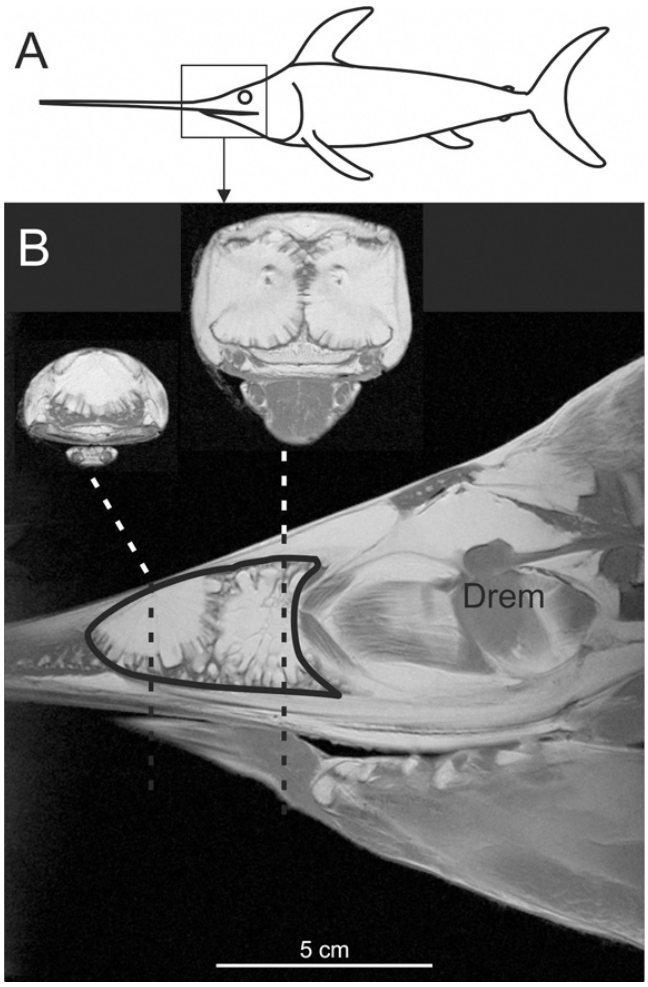

Fig. 1. The position of the oil gland in the swordfish head.
A. Lateral outline of a 1.6 m long swordfish.
B. A MRI section approximately through the median plane. The contour of the oil producing gland is drawn as a black line. Two scans show cross sections at positions indicated by the dashed lines. Drem indicates the position of the heat producing muscle.

The swordfish is a voracious but toothless predator feeding primarily on agile, fast swimming squid. Its swimming speeds are estimated to reach values of well over 100 km per hour. It is a ‘formula 1’ fish full of velocity enhancing gadgets. The sword for example (with a rough and porous surface structure reaching 40-45% of the body length) has been interpreted as a micro turbulence generator suppressing flow separation and reducing drag.

We were the first to make a full body scan of a fish in a magnetic resonance imaging (MRI) machine. The scans of a 1.6 m long adult swordfish captured in the Mediterranean near Corsica, revealed the presence of a unique large gland in the anterior part of the upper jaw immediately posterior to the origin of the sword (Fig. 1).The gland consists of an anterior and two lateral compartments with a total volume of approximately 46 cm^3, occupying about 56% of the volume of the relevant section of the upper jaw. Dissection showed that all compartments were saturated with oil.

A network of capillary, oil transporting vessels in the skin is distributed over a large part of the head, from the origin of the sword up to the edges of the gill covers. This network is connected to the oil gland and is present in the concave anterior and lateral parts of the head. The diameter of the vessels varies between 0.05 and 0.1 mm. Wider main vessels run from the three main parts of the gland towards the areas dorsal and ventral to the eyes and to the skin covering the gland. Side vessels branch repeatedly and cross-connections between different branches occur. The vessels narrow down towards blind ends. Along the vessels numerous round pores open to the exterior of the skin, varying in abundance between 4 and 25 pores per cm^2. They are surrounded by a circle of denticles (Fig. 2). Similar solitary denticles occur between the pores all over the skin of the head.

The oil congeals at temperatures below 8°C. To study the oil flow from the gland to the skin pores, the temperature of the oil gland was increased using a hair dryer inducing oil excretion from the pores. The fish probably uses a heat producing muscle situated just behind the eyes (Fig. 1), The enigmatic distribution of swordfish north and south of the equator could well be limited by 8°C isotherms in the oceans.

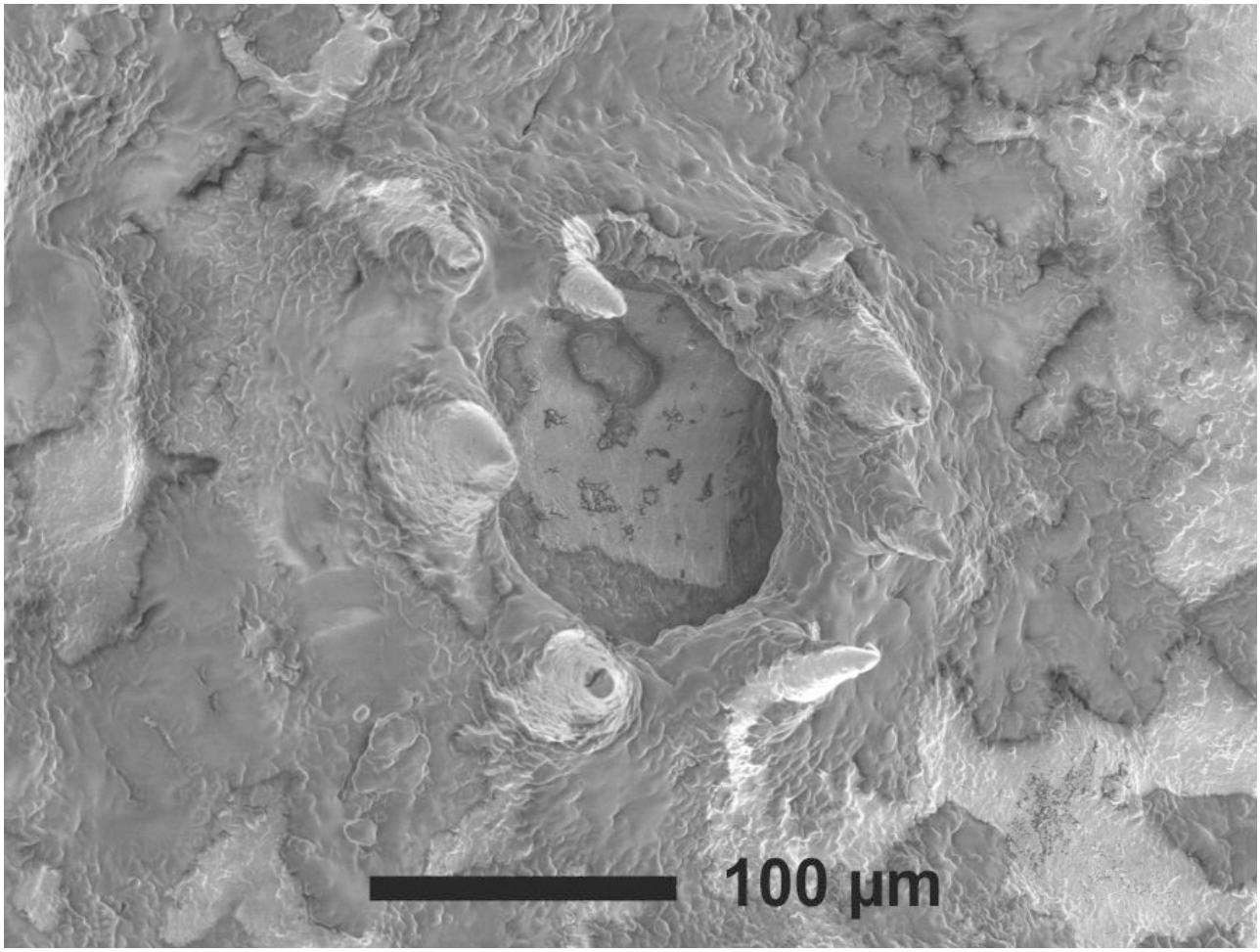

Fig. 2. Detail of one pore. The pore diameter is about 0.1 mm and it is surrounded by 7 denticles.

The mechanism causing the oil to flow through the network of capillaries and to exude through the pores in the skin can be explained by the unique concave shape of the head of the swordfish. During fast swimming an area of low pressure is induced by the concave front part, thus sucking the oil out of the pores.

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Publication

Lubricating the swordfish head.
Videler JJ, Haydar D, Snoek R, Hoving HJ, Szabo BG
J Exp Biol. 2016 Jul