The discovery in a museum collection of the largest known skeleton of *Ichthyosaurus* in the world and its redisplay, including 3D-printing missing bones.

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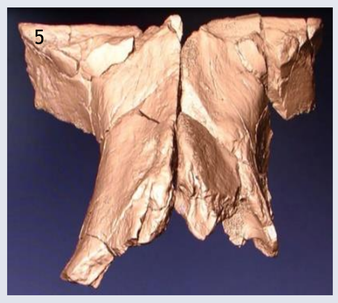
Introduction

In 1955 a relatively complete ichthyosaur skeleton was discovered when digging drainage ditches in Lower Jurassic deposits on a farm in Shipston-on-Stour, Warwickshire. Unusually for Lower Jurassic specimens the skull bones largely retained their three dimensional integrity and the 80 cm-long skull was mounted for display at Birmingham Museum & Art Gallery (Fig 1). A recent conservation project for Birmingham's Thinktank Science Museum to dismantle the skull and rebuild it more accurately involved micro-CT scanning skull elements, mirroring the data and printing 3D models to replace carved pieces of wood that previously represented missing elements on one side of the skull. This process digitally recorded the skull bones for future research before replacing them within the skull

Whilst investigating the history of the specimen and looking for missing pieces of the skull, the postcranial material - which was separated from the skull a long time ago - was rediscovered. The morphologies of the skull, humerus, femur and pectoral girdle demonstrate that this individual is an example of the genus *Ichthyosaurus*. The mandible length suggests a minimum preflexural body length of 3.5 to 4 m. The largest example of *Ichthyosaurus* previously reported is 3 m (Massare & Lomax, 2015). The specimen was subsequently cleaned and conserved for display. To help visitors to understand the skeleton more easily, the missing portions of the postcranial skeleton were recreated. The left forefin and pectoral girdle bones were CT scanned, the data mirrored, and models of the right forefin were 3D printed and painted. The same process was undertaken for missing portions of the hindfins. Missing vertebrae were represented by casts of adjacent vertebrae made from Jesmonite acrylic resin using silicone rubber moulds. The skeleton is now the centrepiece of the new permanent Marine Worlds gallery at Thinktank, including an interactive focused on the conservation.

Studying, recording, dismantling and rebuilding the skull

1.The skull as originally reconstructed, late 1950s.
2. The skull being CT scanned.
3. CT scan of the skull.
4.The internal surface of the parietal.
5. Digital 3D image of the parietal.
6.The parietal and other well preserved bones of the rear of the left side of the skull.



7. The 3D-printed skull bones (a. quadrate; b. stapes; c. opisthotic; d. pterygoid, e. articular). Made by MicroCT scanning bones on the left of the skull, mirroring the data and 3D printing in 'Visijet PXL Core' (calcium sulfate hemihydrate, essentially gypsum).

The skull had been reconstructed from many small fragments of bone plus some metal rods and various pieces of carved wood to support them. Large amounts of glue and gap filler had to be removed so that the skull could be carefully dismantled (Fig 8) for the anatomical errors to be rectified. For instance the left and right splenials had been swapped around and were upside-down; the left side of the mandible was badly offset and overlapping itself by several inches; the basisphenoid was in the wrong place; the mandible and skull needed to be separated slightly; and some broken bones required repairing.

In the process of examining the skull material it was discovered that, unusually, both of the hyoid bones are preserved complete and undistorted and the brain cavity inside the parietal displays the impression of the optic lobe.

The skull was rebuilt with the bones in their correct positions (Fig 9) using the reversible polymer Paraloid B72 as an adhesive and consolidant. The 3D-printed model bones on the right of the skull were painted with artists acrylics and attached to the real bones with plaster of paris.

Supporting metalwork was replaced with Perspex rods to facilitate CT scanning and a new storage plinth was made.

Conservation of the forefin

The bones of the left forefin had been stuck to shaped Perspex rather messily with excessive amounts of glue (Figs 10 & 11). Also, they were displayed in ventral aspect yet the skeleton would be displayed in life position. Therefore all the bones had to be removed and the bones and Perspex had to be cleaned of their old adhesive. Then the bones had to be reattached in a reversed order and the right way up. The glue was softened with acetone and removed with scalpels, then the bones and Perspex were cleaned with an airabrasive using sodium bicarbonate powder. The bones were reattached with a paste of Paraloid B72 adhesive and glass beads (Larkin & Makridou, 1999).

Unfortunately, the exact original arrangement of the elements in the forefin is unknown, so their repositioning was based on observations of complete *Ichthyosaurus* forefins preserved *in situ*.

Replicating missing postcranial bones

Neither of the limbs on the right side of the body were preserved. Therefore the conserved and reconfigured left forelimb and the left scapula and clavicle as well as the femur of the left hindfin were CT scanned. The scans were sent to Steven Dey at ThinkSee3D who had 3D-printed the mirrored bones for the skull. He cleaned all the data, mirrored it and printed 3D models of the complete forelimb (including the phalanges on their mirrored Perspex mount (Fig 12)) and also the femur for the right side of the ichthyosaur.

12. Left to right: the surface mesh model of the mirrored left forefin; the printed right forefin next to the left forefin; and the painted 3D-printed model next to the real bones (real to the left).

Display

The new display (Fig 13) at Thinktank, Birmingham's Science Museum, with the skeleton articulated in the foreground, Bob Nicholls' artistic reconstruction of the ichthyosaur behind and a traditional 'flattened' ichthyosaur fossil hung on the wall.

In addition, throughout the project various video blogs describing the work in detail were uploaded to Youtube. These can be found by Googling 'Thinktank ichthyosaur'.

Discussion

This partial skeleton from Lower Jurassic deposits is the largest *Ichthyosaurus* specimen reported, with a fairly complete skull including elements that are extremely well preserved in three dimensions, not flattened. These elements have been MicroCT scanned and the whole skull (rebuilt to be more anatomically correct), femur and complete left forefin and pectoral girdle have been CT scanned, to aid research. This data was also useful for display purposes: by mirroring data and creating digital 3D models some missing elements were able to be 3D printed.

However, although the use of 3D printing technology in museums is increasing with every passing year, very little research has been undertaken so far on the stability of materials used, or their suitability to be in close proximity with museum specimens inside sealed display cases. Therefore Oddy tests and other analyses are currently being undertaken on commonly used 3D printing materials by Nigel Larkin, Gabrielle Flexer & Julian Carter. The results should be published soon.

References

Larkin, N. R. & Makridou, E. 1999. Comparing gap-fillers used in conserving sub-fossil material. *The Geological Curato*r 7, 81-90.

Massare, J. A., Lomax, D. R. & Klein, A. 2015. A large forefin of *Ichthyosaurus* from the U.K., and estimates of the size range of the genus. *Paludicola* 10, 119-135.

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