Journey into the interior: PPC-SRμCT as a multi-scale tool for investigating the anatomy and histology of the earliest vertebrates

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The early evolution of vertebrates, approximately occupying the time span from 500 to 350 million years ago, involved a series of major anatomical and histological innovations such as the origin of jaws, fins, limbs and biomineralized tissues, as well as the origin of the main extant vertebrate clades. Fossils of these early vertebrates are thus potentially very informative about large-scale evolutionary questions. However, the fossils are not easy to interpret: they are often small, tend to occur in hard and intractable sediments, and often show structures that are so different from those of living vertebrates as to make anatomical interpretation difficult. Past investigations of early vertebrates that have gone beyond surface description of specimens have usually relied heavily on different sectioning techniques; internal anatomy has been studied by means of serial grinding, producing series of section planes with a 250 μm spacing, modelled physically as stacks of wax plates, whereas microanatomy and histology have been studied from thin sections viewed by transmitted light. These techniques are destructive and time-consuming. In recent years conventional CT has been applied to the study of vertebrate fossils, allowing rapid non-destructive imaging and computer modelling of macroscopic anatomy, but it has had limited success with early vertebrates because of their small size and frequently low bone-rock contrast: only rarely has it been possible to equal the information content of grinding series data. In collaboration with Paul TAFFOREAU we are successfully applying propagation phase contrast synchrotron microtomography (PPC-SRμCT) at multiple scales from about 20 μm voxel size (for macroscopic anatomy) to 0.7 μm (for histology) to the study of early vertebrates. Propagation phase contrast allows us to image diaphanous ossifications and exceptionally preserved soft tissues in heavily mineralized rock, and subtle histological features such as growth arrest surfaces, cell lacunae and vascular canals in bone tissue. At low resolutions, we are producing anatomical models of radically better resolution and greater objectivity than those obtained from grinding series. At high resolutions, we are able to model hard-tissue histology in three dimensions. This not only casts light on hard-tissue composition, organization and growth, but also allows us to identify muscle attachments on the bones. We are thus able both to visualize preserved musculature at medium to low resolutions, and to investigate muscle attachment histology in three dimensions at high resolutions. The histological data allow us to infer the presence and approximate orientation of muscles even in the absence of soft-tissue preservation. I will illustrate these points with reference to our work on placoderms and lobe-finned fishes from the Devonian period (419-359 million years ago).