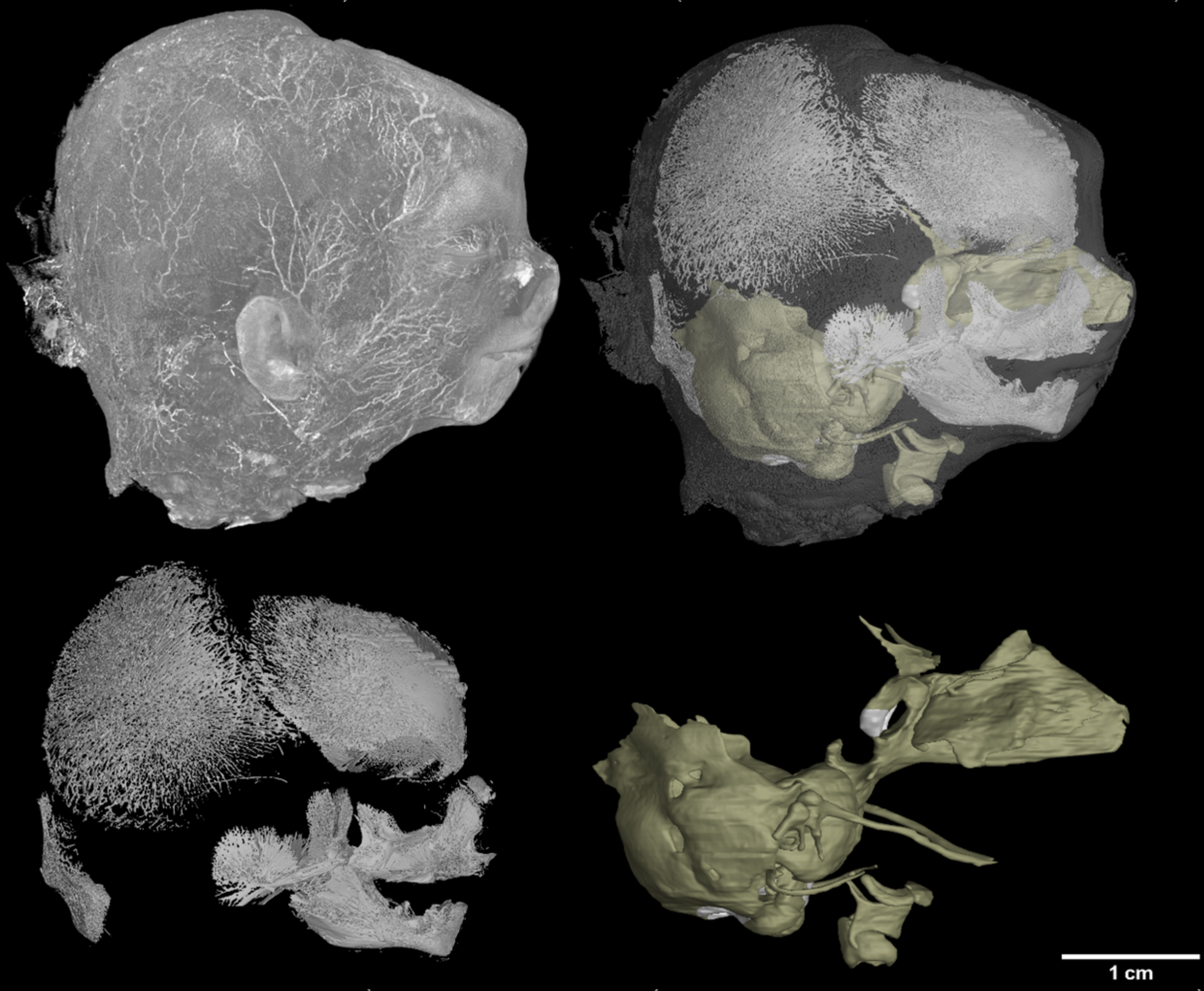
CEITEC CTLAB

BRNO UNIVERSITY OF TECHNOLOGY



3D cartilage atlas of mid-trimester human embryos on page. 7.

NEWSLETTER AUTUMN 2024

It is a pleasure for me to present you a new issue of the newsletter of our Laboratory of X-ray Micro and Nano-Computed Tomography at CEITEC BUT. You can read about some of our recent activities, such as the analysis of pouch batteries, testing of an X-ray source for large metal-printed aerospace components, and the analysis of a fossilized miniature jaw of ancient worms. We would also like to inform you about a planned workshop in 2025 (see p. 2), to which you are warmly invited.

Enjoy reading!

Tomáš Zikmund
Head of the laboratory

MULTI-SCALE IMAGING WORKSHOP 2025

In April 2025 we are going to be organizing CEITEC Workshop on Multi-scale Imaging! The first day will be dedicated to industry - producers, users and customers mainly with the focus on X-ray CT, followed by the Scientific Days linked with the EXCITE Network consortium. The event will be connecting experts from various fields of the EXCITE Network (electron microscopy, X-ray CT, spectroscopic techniques, etc.) with the transnational access users and the industrial partners, offering interesting presentations, lab tours and hands-on software trainings. Registration will open in November.

More on www.excite2.ceitec.cz

POUCH BATTERY ANALYSIS

Computed tomography (CT) provides a sophisticated, non-destructive approach to accurately measure and assess the structural integrity of batteries. This can be defined for batteries as the overall integrity of the battery pack, the symmetry of the electrodes, delamination and deformation of the electrodes, the uniformity of the distribution of the separator between the electrodes and more. Using high-resolution 3D non-destructive imaging, CT allows detailed internal inspection of structural integrity without damage or degradation of the batteries. With the new battery analysis software module, we now have the ability to perform these precise quality assessments. In this paper we discuss the „pouch" type of battery. This battery is specific because of its flat construction without a metal casing. A tomographic cross-section of the data of the „pouch" batteries is shown in Fig. 1. In the section we can see the cathodes (wider electrodes) and anodes (thin overlapping electrodes) in the battery pack. This data was acquired with a linear voxel resolution of 20 μm. A key feature of the above module is the ability to detect the deviation of the output anode tangent angles with respect to a defined axis (in this case, angular deviation with respect to the y-axis) and electrode discontinuities, see Fig. 2b), which is a significant factor that can lead to uneven current distribution. This negatively affects the efficiency and safety of the battery. Another capability of this module is to analyze the anode to cathode overlap. Different anode overlaps significantly affect current dissipation, the formation of thermal nodes, and the effect on heat dissipation. In addition, the analysis allows for the assessment of individual electrode thicknesses (Fig. 2a)).

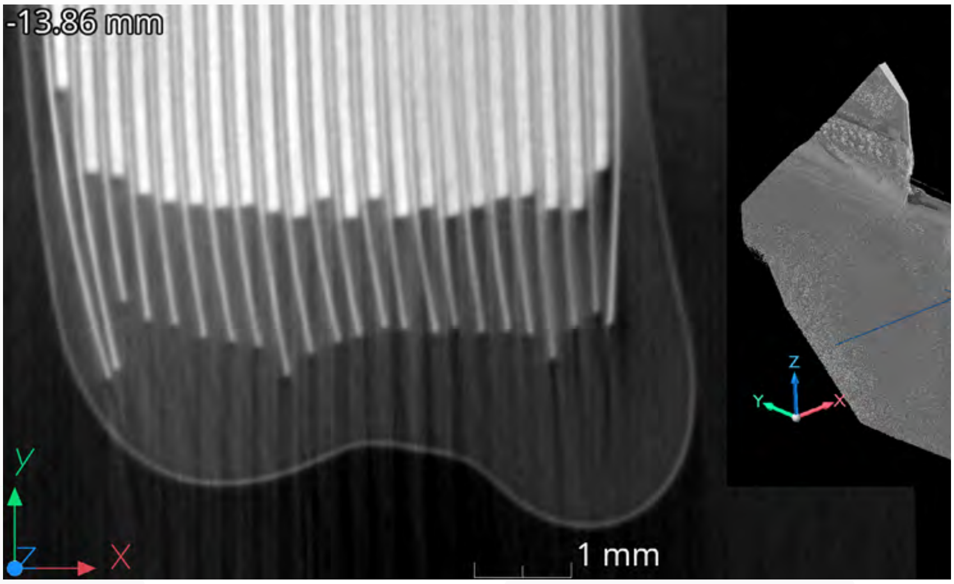


Fig. 1: Tomographic section of the corner of the battery pouch (with the position of the tomographic section shown by the blue plane in the 3D render).

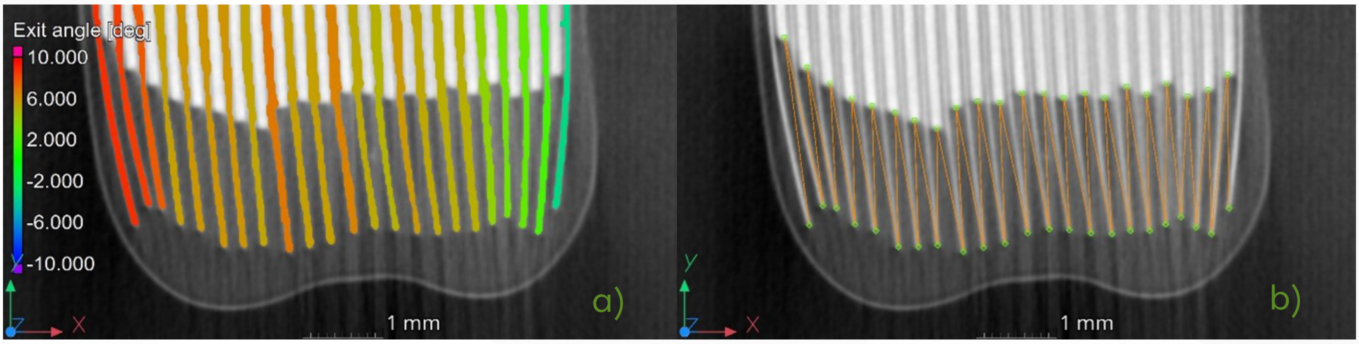


Fig. 2: Visualize the output angles of the anode using the color scale on the left. Check of electrode discontinuities by sequential electrode vertex continuity (anode-cathode-anode-...) on the right.

Identifying these microstructural anomalies is key to understanding potential risks to mechanical integrity, overall battery performance and efficiency. Due to their flexible and fragile nature, these batteries are more susceptible to mechanical stress and external damage. It is therefore essential to assess the integrity of the casing as well. CT measurements allow an accurate assessment of the structure of the casing and the identification of potential weak points or breaches that could compromise the safety and reliability of the batteries. We are able to perform non-destructive testing of batteries under a wide range of conditions such as charged and discharged, under voltage or comparing new and used batteries.

Author: Michal Petřík

X-RAY SOURCE TESTING
FOR LARGE METAL-PRINTED AIRCRAFT PARTS

The current trend in the production of aircraft parts is the use of metal 3D printing, which can simplify the standard production of an assembly of parts by several steps at a time. This reduces the number of parts, weight and also increases the performance of the functional unit. Additive manufacturing machines have seen a huge development in terms of the possibilities of the size of the manufactured part. Today, it is possible to produce parts up to 600 mm in diameter with the largest machines.

CT inspection is then an important part of checking these parts to exclude internal defects and verify the overall geometry. Increasing the dimensions of the part, manufactured in aviation mainly from Inconel, places greater demands on the X-ray radiation sources. Parts are very difficult to irradiate with standard open (micro-focus) x-ray sources with an accelerating voltage of up to 300 kV. A more suitable choice, due to greater performance, is a closed (mini-focus) tube with an accelerating voltage of 450 kV, however, the differentiability of the defect is then at the level of tenths of millimeters. The advantages of both these types of tubes are combined by a relatively new tube called meso-focus 450kV.

We tested the possibilities of this type of source on a stator wheel made of SS316L material with a diameter of 385 mm and a weight of 1.9 kg. The stator wheel (Fig. 3) is part of every jet engine and plays a key role in controlling and increasing the efficiency of air compression before it enters the combustion chamber. The measurement of the part showed that the tube has sufficient power to illuminate the part and at the same time preserves the detection capabilities of micro-focus tubes, i.e. at the level of hundreds of μm.

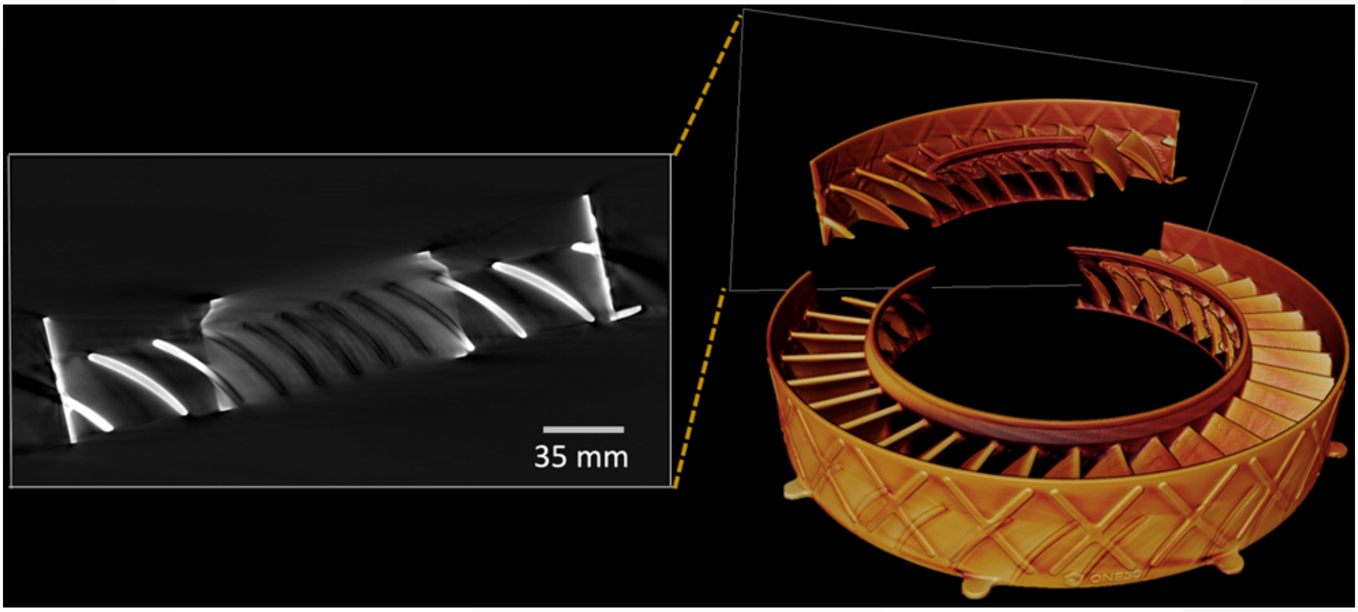


Fig. 3: On the left, a tomographic cross-section showing the internal structure of the material (voxel size 129 μm). On the right, an artificially colored 3D model of the CT data showing the plane in which the tomographic slice is taken.

Thanks to the companies One3D for the production and loan of the stator wheel and Waygate Technologies (Germany) for the implementation of CT measurements.

Author: Tomáš Zikmund

SELECTION OF SAMPLE POSITION USING CT SIMULATIONS

One of the important influences on the quality of the resulting tomographic data is the position of the sample during the measurement, which can suppress or, on the contrary, accentuate the artificially increased amount of noise by so-called tomographic artifacts and overall reduced contrast of materials. One of the goals is thus to prevent the obscuration of the area of interest with absorbing components (e.g. steel screws). Determining a suitable position is usually not a problem for an experienced operator. For complex samples and multi-material assemblies, where the area of interest is surrounded by a mass of material from almost all sides, it can be more difficult to evaluate by eye and for the best result you need to use another tool.

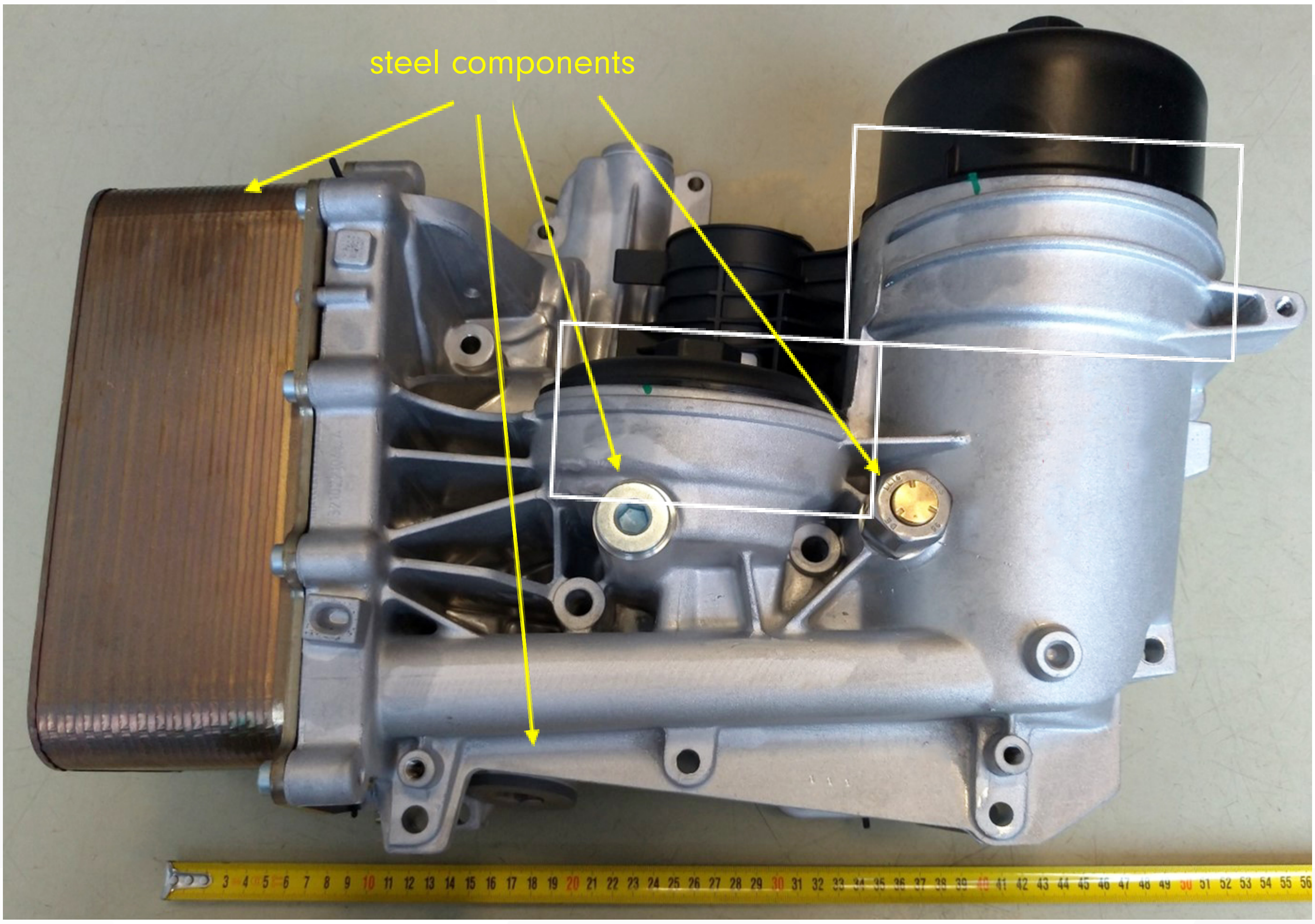


Fig. 4: Photo of the studied sample. Regions of interest are indicated by white rectangles; yellow arrows point to steel components, degrading the quality of CT data in adjacent areas.

This was also the case with the almost 20 kg heavy and half meter long oil filter system (Fig. 4). The basis of the assembly is an aluminum body, a stainless steel heatsink and several steel screws and plugs. An area of interest for us were O-rings under plastic covers, whose deformation has a fundamental effect on the resistance of the part during operation conditions. To achieve the highest possible data quality, we used aRTist simulation software. The inputs for the software are the sample model, its materials and, of course, also the basic parameters of the CT system. Subsequently after defining the position of the sample, a series of simulated X-ray projections can be taken, which can be reconstructed to achieve realistically looking tomographic data (Fig. 5).

As already mentioned, the main indicator of data quality for us was the (in)ability to evaluate the position of the O-ring around 360°. The aim of the simulations was to find a position in which the largest possible part of the sealing would be taken in sufficient quality for the linear measurement of the seal profile in the given axial section (see Fig. 6). in our case, we were able to reduce the number of problematic cuts by one third compared to the original selected position. In the case of a combination of several different acquisition positions of the sample, it would then be possible to achieve even 100% inspection throughout the perimeter.

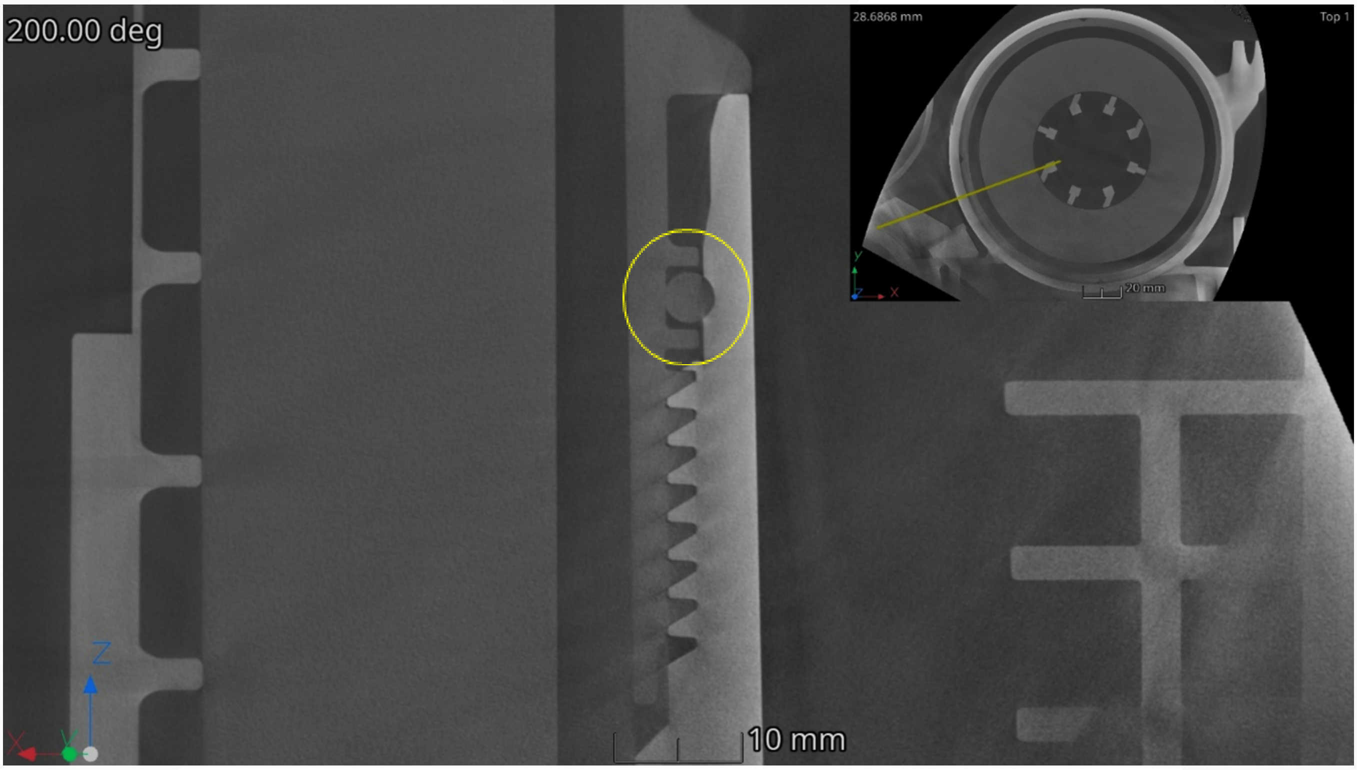


Fig. 5: Tomographic section reconstructed from simulated X-ray projections. Inspected sealing is shown in the yellow circle. Compared to reality, its cross-section is circular in the model, and therefore extends into the aluminum body of the filter.

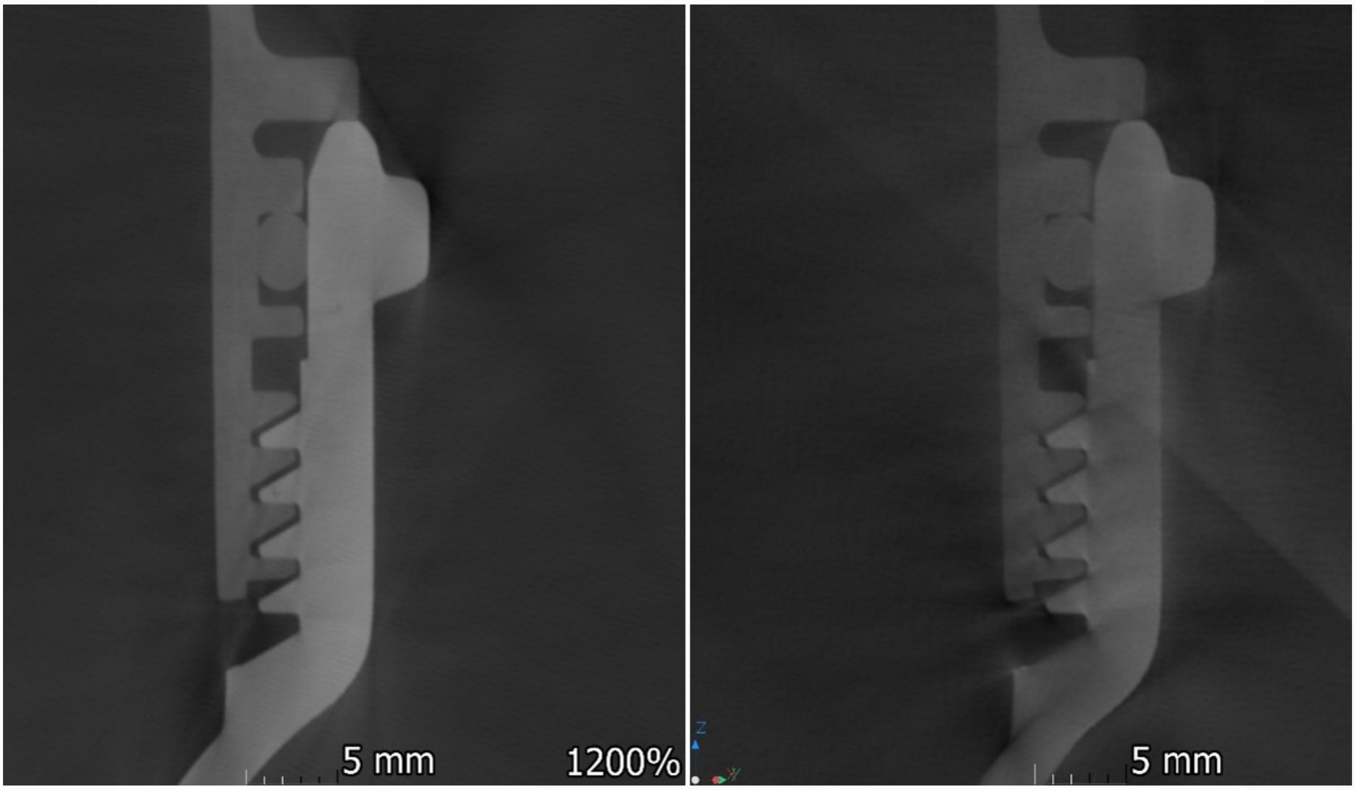


Fig. 6: Comparison of tomographic cross-sections of the same sample location, taken at a different position of the sample during measurement. Left picture shows less artifacts and higher contrast between materials.

Author: Martin Kareš

3D CARTILAGE ATLAS OF MID-TRIMESTER HUMAN EMBRYOS

Our knowledge of human body development is often studied in animal model organisms. Scientists from our laboratory have been collaborating with biologists worldwide for a long time. In our previous studies, we have shown the development of cartilaginous tissue (chondrocranium) in mouse embryos, which is a crucial structure for the further development of the skull and other tissues in the developing organism. There are many ways to study animal organisms. In comparison, the possibilities for studying human embryos are very limited, both in terms of methodology and ethical issues. Therefore, current research has to rely on drawings made by anatomists a few decades ago.

Scientists from our laboratory joined forces with an international team of biologists and the University of British Columbia (UBC) in Canada. The university works closely with a local hospital and has human embryos in its collection. These samples were collected in the 80s by Dr. Virginia Diewert, professor emerita at UBC. These were embryos of elective or spontaneous terminations, where the mother gave anonymous consent for the use of the fetus for scientific purposes. The embryos from this collection were transported to our lab for microCT scanning. Demanding data processing followed with a focus not only on cartilage but also on ossified areas and other soft tissues. Fig. 7 shows a 3D model of cartilaginous and ossified tissue inside a 13-week-old human embryo – the youngest embryo from the collection. Now, the CT data together with 3D models can be accessed through our published work.

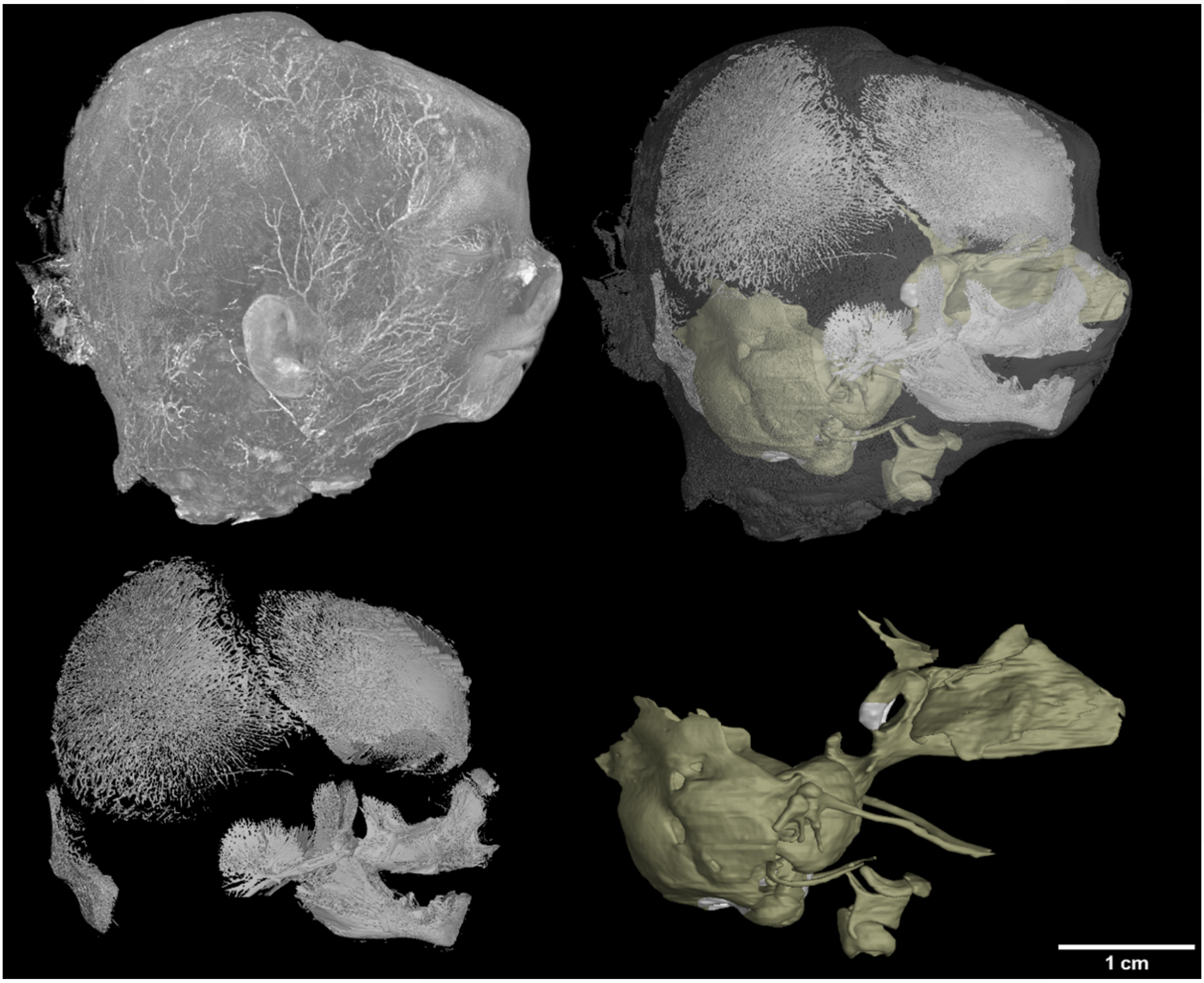


Fig. 7: 3D visualization of cartilaginous and ossified tissue of a 13-week-old human embryo. The image reveals the individual layers of the 3D model - skin (upper left corner), semi-transparent skin with bone and cartilage (upper right corner), bone (lower left corner), and cartilaginous tissue (lower right corner).

Author: Markéta Kaiser

MINIATURE FOSSIL JAWS OF ANCIENT WORMS

Bristle worms (Polychaetes, Fig. 8) are a class of predominantly marine annelids, which makes them distant relatives of earthworms. This diverse group of organisms contains species which are only a few millimeters long, as well as giants that reach several meters in length in their adulthood. However, most known bristle worm species are closer to the lower end of this spectrum. Polychaetes are undeniably successful; they are some of the most widespread annelids in the present day, and members of their group are known from the fossil record to have lived as far back as the Cambrian, which was more than 490 million years ago. It is this tenacity and diversity which makes these organisms so interesting for the field of paleontology. Furthermore, the fossil remains of ancient bristle worms are currently not a common subject of study, and changing this may reveal new information about the development of life on Earth. The soft bodies of these animals are usually not preserved in the fossil record, and the only fossilized remains are their jaws also known as scolecodonts. Scolecodonts are small, brittle, and hollow fossils, which usually reach a few hundred micrometers in length. A microscope is essential for studying these objects, but even with high magnification and resolution in the micrometer range, these two-dimensional methods limit the ability of researchers to study these samples. Using high-resolution tomography (micro-CT and submicron-CT), we can visualize scolecodonts in 3D, including their internal structure, which other methods cannot access (Fig. 9). CT can even scan jaws which are still partially embedded in sediment, and the results can be processed to virtually separate the fossils from the surrounding matrix (Fig. 10). This simplifies the laborious maceration which removes this matrix from the specimen physically. Models of individual scolecodonts can then be rearticulated to reconstruct jaw apparatuses as they appeared in the live animal millions of years ago.

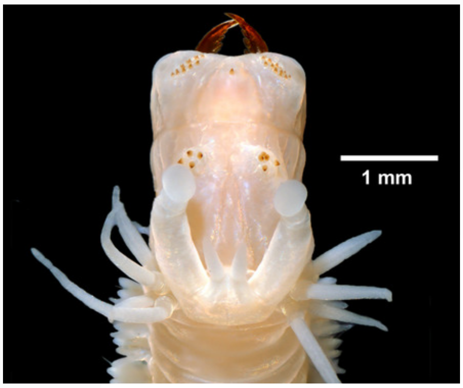


Fig. 8: Nereis pelagica is an example of an extant polychaete. Photo: Eric A. Lazo-Wasem, Yale Peabody museum collection.

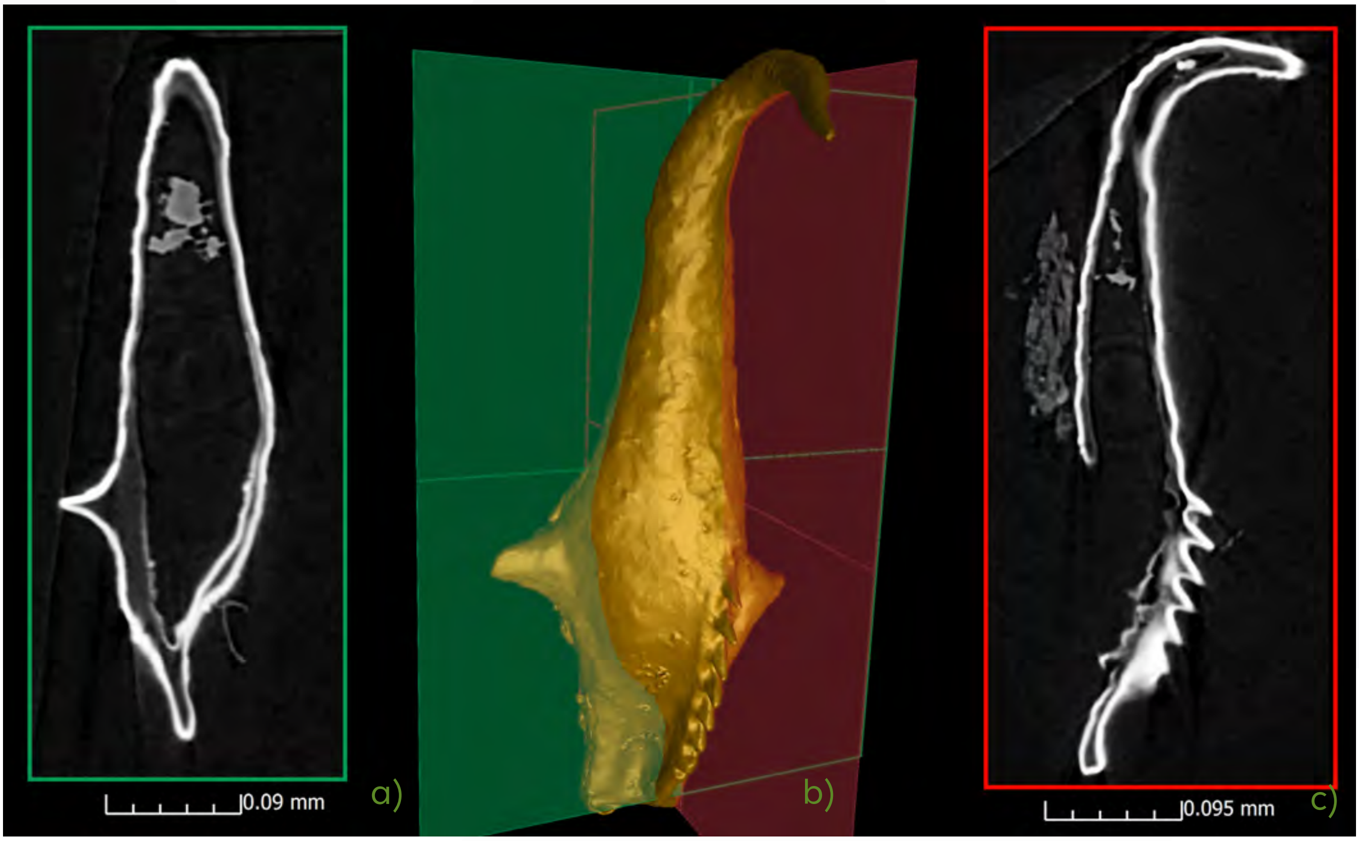


Fig. 9: Tomographic slices and a 3D model of a scolecodont acquired using high-resolution submicron-CT available at CEITEC BUT. This scolecodont belongs to the species Spitiprion khannai, and it comes from the Spiti valley in India, from the late Ordovician (approx. 450 milion years ago).

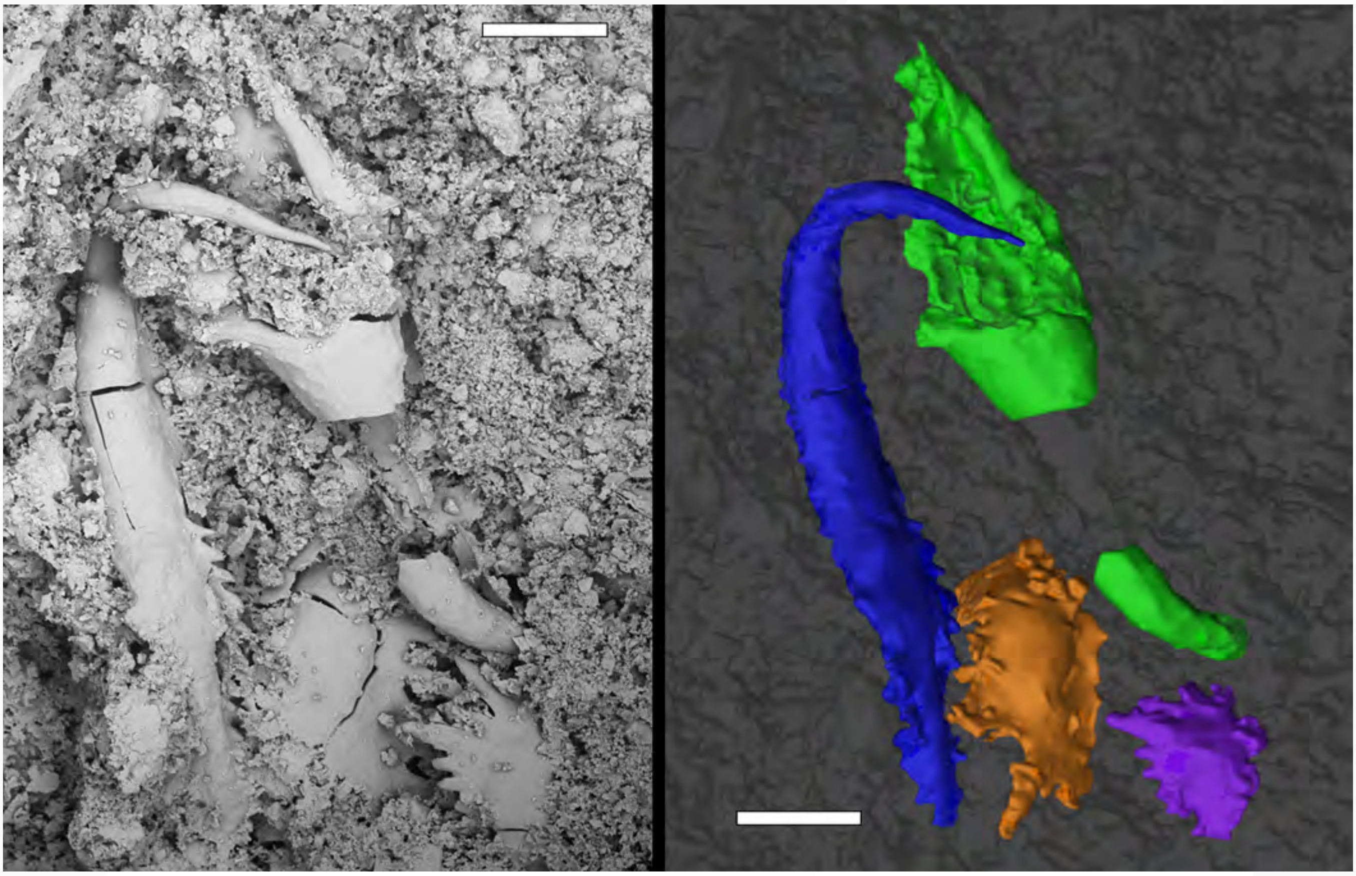


Fig. 10: Images of scolecodonts of the species Spitiprion khannai acquired using an electron microscope (left) at the Czech Geological Survey in Prague, and their 3D models (right) acquired using micro-CT at CEITEC BUT. The scale bar is 100 µm. Adapted with permission from doi.org/10.4202/app.01135.2024.

Author: Marek Zemek

SUPPORT OF FOREIGN STUDENTS IN OUR LABORATORY

In our laboratory, students from all over the world can participate in cutting-edge research and development in the field of X-ray Computed Tomography (CT). We are proud to provide opportunities not only for local but also international students to become part of our community and gain valuable practical experience in our field. They get the opportunity to engage in research through various programs such as Erasmus+, exchange stays, summer internships (e.g. IAESTE), and international scholarships. These programs allow students not only to develop their technical skills and knowledge, but also to familiarize themselves with the culture of our country and adapt to new work environments.

At the beginning of July, a Computer Engineering student at the Ecole Nationale d'Ingénieurs de Tunis decided to join our research group through the IAESTE program and embark on a two-month internship. In mid-July, an undergraduate student of electrical and electronic engineering at Hacettepe Üniversitesi in Turkey joined us as part of the Erasmus+ program.

Author: Michaela Škaroupková

CTLAB SPONSORS TU BRNO RACING

Our laboratory sponsors a student team TU Brno Racing, for many years. The team presented a new model of the student formula, the fourth electric single-seater named Dragon e4. As every year, the student team will take part in the global Formula Student competition with this single-seater, where they placed in the world top 20 in the last season 15th place. In cooperation with the team, our laboratory participates in the development of automotive parts through non-destructive testing with X-ray computed tomography. In past years, we have tested, for example, the quality of glued joints as part of the development of composite axle arms, the geometry of shock absorber heads for their subsequent optimization. Furthermore, the quality of the production of carbon wheels, the control of bubbles in the disc between the carbon layers or the analysis of the motor stator.

Fig. 11: Dragon e4 with CTLAB and TU Brno Racing management. From th left: Prof. Jozef Kaiser, Marek Viktořík, Michaela Škaroupková, Assoc. Prof. Tomáš Zikmund, Tomáš Velfl.

Author: Michaela Škaroupková

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