TOMCAT beamline permits to resolve vessels down to a diameter of 2.5 µm (see Fig. 2). Both kinds of tomography data clearly allow for the visual discrimination between healthy and cancerous tissues [4]. Many vessels in the cancerous section appear unshaped or twisted [5, 6], while they are better ordered in the healthy tissue. The casting elastomere penetrated into the cancerous tissue outside the vessels at several locations (Fig. 2), presumably as the result of vessel wall damages in the necrotic part of the tumor.

Figure 1: 3D image of the tumor vessel system measured with a SkyScan 1174 (a) using a detector pixel size of 12 µm and the synchrotron radiation source at the beamline TOMCAT (b) (SLS, Switzerland) using a detector pixel size of 5.92 µm.

Figure 2: Shows a cropped region from the tumor cast (highlighted in Fig. 1 (b)) measured at TOMCAT beamline using 5.92 µm (a) and 0.74 µm (b) detector pixel size.
Discussion and Conclusions
Both conventional and synchrotron radiation-based μCT allow visualizing the 3D structure of an appropriately prepared cast from the vascular network of tumors. The SkyScan™ 1174 scanner has the advantage of availability combined with relatively short acquisition time (below 1 h) and easy operation. The SkyScan 1174 offers availability for overview scans, where moderate spatial resolution is sufficient. For high-resolution imaging down to the smallest capillaries, synchrotron radiation sources are better suited. The improvement in the spatial resolution by almost 2 orders of magnitude, however, comes at the cost of a significantly increased acquisition time. The tomography data can be converted into vector-data format for quantifying the network bifurcations and vessel shapes. Although the vessel diameters are included in the tomography data, their exact diameter is not directly accessible, because the casting elastomere undergoes shrinkage during the curing process.

Acknowledgement
We kindly acknowledge Alexandra Ulmann and Eric P. Meyer for the corrosion cast of the vessels and Marco Stampanoni and Federica Marone for their support during data acquisition at TOMCAT.

References:
A *bona fide* model for age-related osteoporosis in accelerated aging trichothyiodystrophy (TTD) mice

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**Aims**

Osteoporosis typically manifests itself at old age. One potential mechanism by which aging can occur is through the accumulation of DNA damage, and premature aging can occur when repair of these damages is distorted [1]. By using DNA repair deficient mouse models as a tool, research in our laboratory focuses on the mechanism of aging and the etiology of aging related pathology. In this study, we used a mouse model that closely mimics the human premature aging syndrome trichothyiodystrophy (TTD). Much like human TTD patients, these mice show accelerated onset and progression of age-related diseases [2]. The goal of this study was to assess if TTD mice can be used as a model for spontaneous, age-related osteoporosis that mimics the human situation more closely.

**Method**

From a cohort of 120 female wild type (WT) C57Bl/6 and 120 TTD animals groups of mice (n=10/group) were sacrificed at defined time points (13, 26, 39, 45, 52 and 65 weeks of age), followed by dissection of femur and tibia. Separate groups of TTD mice (aged 26-65 weeks) were injected with ALN and PTH, to investigate if these drugs would have the same bone preserving effect in TTD mice as in human osteoporosis patients. Of each mouse, the bone phenotype was determined using micro-CT analysis (right femur), using the Skyscan 1076 scanner at a voxelsize of 9 µm. Bone strength was assessed using break tests (left femur), and transcriptional profiling was performed using micro-arrays (of tibia’s, n=50). Serum and plasma was collected for future biomarker approaches.

**Results**

At 13 weeks of age, the bone phenotype of WT and TTD animals was not significantly different, but from 26 weeks onwards TTD animals had a faster age-related decline both in trabecular and cortical bone (BV/TV at 65 wks: WT: 12.5±0.5%; TTD: 9.1±0.6%, Ct.Th.: 218.3±3.9µm, TTD: 194.1±5.9µm). Bone strength was significantly lower at 65 weeks of age (WT: 97.1 ± 5.7 N/mm, TTD: 53.4 ± 3.6 N/mm). Both ALN and PTH were able to overcome the bone loss and maintain bone strength. Micro array analysis of bone tissue from untreated TTD animals showed that typical bone markers (SOST, Bglap, Coll-1, ALP, Periostin, Runx2 and TRAP) had a similar pattern of expressional change.
Conclusion

TTD mice showed accelerated bone loss during aging which could be reversed with drug treatment. At young age their bone phenotype did not differ from WT animals. This makes the TTD mouse model a suitable screening tool for determining bone-preserving qualities of both existing and novel treatments. In addition, its spontaneous development allows the discovery of biomarkers that may predict osteoporosis onset.

References:

Osedax borings in fossil early Oligocene marine bird bones

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Aims
Osedax is a marine annelid (family Siboglinidae) that consumes bones on the seafloor (Rouse et al. 2004). Its evolutionary origin and the range of substrates that it is able to consume are still unclear (Glover et al. 2008; Jones et al. 2008; Vrijenhoek et al. 2008, 2009). Using molecular clock estimates, its origin has been linked to the Cenozoic rise of whales (Rouse et al. 2004), recently supported by the discovery of fossil traces of Osedax in Oligocene whale bones (Kiel et al. 2010). Using an alternative calibration for the molecular clock, however, a Cretaceous origin also seems possible (Vrijenhoek et al. 2009). In this case, Osedax might have consumed bones of large marine reptiles such as plesiosaurs and mosasaurs and after their extinction at the end of the Cretaceous it was suggested (Vrijenhoek et al. 2009) that bones of turtles, marine crocodiles, and perhaps large fishes could have been utilized. Although the bacterial symbionts that provide Osedax with nutrition can survive on collagen and lipids as sole carbon sources (Goffredi et al. 2007), there was no evidence so far that Osedax consumes anything other than mammalian bone. Here, we show that Osedax colonized bones of large, flightless marine birds in the early Oligocene.

Method
The fossilized bones of the penguin-like bird \textit{Tonsala hildegardae} (family Plotopteridae) were extracted from the enclosing rock by acid etching. One specimen was scanned using the SkyScan 1172 device of the experimental and theoretical petrology group at Kiel University with a beam energy of 70 kV, a flux of 141 µA and a copper-aluminum filter with a resolution of 8 µm using a 360-degree rotation with a step size of 0.75 degrees. Image analysis and volume rendering was done using the SkyScan software CT-analyser.

Results
Many of the bones show significant corrosion (Goedert and Cornish 2002), and almost all of the bones have at least a few boreholes. Protruding edges of some bones are corroded to the extent that much of the smooth surface has been corroded away, exposing the trabecular bone underneath (Fig. 1b). The bones also show scrape marks most likely produced by scavenging sharks. Boreholes are widely scattered on some of the bones, especially on the femora and tibiotarsi where they are restricted to the bone shaft and are absent from the more dense proximal and distal surfaces. The pelvis has a number of widely distributed boreholes, some in very thin bone such as portions of the ilium and ischium. A high density of boreholes (35 borings per square centimeter), some of them fused, with a maximum diameter of 0.3 mm, was seen on the smooth surface of the micro-CT scanned vertebra of \textit{T. hildegardae} (Fig. 1b). Just below the head of the femur of \textit{T. hildegardae}, the density reaches 40 borings per square centimeter.
The micro-CT scans show that these boreholes lead into a network of cavities underneath the surface (Fig. 1d). A regular cavity of the trabecular bone was also penetrated (Fig. 1e). The surface layer above the network of cavities is often only 0.1 to 0.2 mm thick (Fig. 1f). Most holes on the investigated bones do not exceed 0.3 mm in diameter. Exceptions include one hole on the proximal end of a femur of T. hildegardae, which reaches nearly 1 mm in diameter (near top of Fig. 1a), and one hole that reaches 1.5 mm in diameter near the distal end of the femur. Both of these large holes are situated at the transition zone between shaft and the head.

The boreholes and cavities documented here in bones of the early Oligocene ploptopterid bird T. hildegardae resemble those in whale bones from the same strata and those produced by Osedax today (e.g., Figs. 1d; 2a in Kiel et al. 2010). Plotopterid bones have neurovascular foramina that can be of similar size as boreholes produced by Osedax, but they have smooth edges or start as a small sulcus whereas Osedax boreholes have sharp edges, as if made by a drill. Borings and cavities produced by other deep-sea invertebrates such as sipunculids, sponges, or bivalves differ in shape from Osedax borings (see discussion in Kiel et al. 2010) and from those reported here. Microbes can substantially damage bones in deep water, but their activities affect mainly the surface layer of the bone rather than the interior and individual borings are only a few micrometers in diameter (Allison et al. 1991; Kiel 2008). The borings documented here are thus interpreted as Osedax borings.

Compared to Osedax borings in Oligocene whale bones those reported here reach significantly higher densities, up to 40 borings per square centimeter in the bird femur compared to a maximum of 15.5 borings per square centimeter on a whale dentary (Kiel et al. 2010). The size of most borings in the bird bones is within the range of those on the whale bones (up to 0.45 mm in diameter), except for the two extremely large borings (up to 1.5 mm in diameter) on the bird femora. The shape of the cavities suggests that the producing Osedax species had a branching filiform root like the extant O. roseus (Rouse et al. 2008, their Fig. 4b) and the species that attacked Oligocene whale bones (Kiel et al. 2010). The maximum size of an individual specimen of Osedax in the bird bones is difficult to determine because all boreholes on the surface lead into interconnected cavities; however, an elongate tunnel (Fig. 1e) most likely produced by a single individual is 3 mm long. This is almost twice as large as the Osedax holes from coeval whale bones, which reach a maximum dimension of 1.7 mm (Kiel et al. 2010).
Figure 1. Osedax borings in early Oligocene bones of the plectopterid bird *T. hildegardae*. (a) Femur showing numerous small holes, and a corrosion pit on the upper half. (b) Smooth lateral surface of a vertebra with a neurovascular channel (nvc) in the middle and a high density of Osedax borings; numbers indicate the boreholes shown in (d), (e), and (f); lines indicate the positions of the micro-CT scans shown in (c), (e), and (f). (c) Reconstructed image of a micro-CT scan horizontally through the vertebra, bone material (white to gray), holes and cavities (black). (d) Micro-CT-based rendering of the trace fossils, bone material in transparent blue, borings and cavities in yellow. (e), (f) Micro-CT scan images of the vertebra, showing a relatively straight boring that penetrated a regular cavity of the trabecular bone (e) and a cavity with only a thin “roof” of bone material (f); image from Kiel et al. (2011).
Conclusion
The boreholes documented here in fossil marine bird bones provide the first evidence that Osedax may be capable of growing on non-mammalian bones and to colonize carcasses as small as 80 cm in length. A possible Cretaceous origin of Osedax as suggested by molecular clock estimates was thought to require its ability to grow on fish or reptile bones, for which there is currently no evidence. The Oligocene traces documented here do not provide evidence for a Cretaceous origin of Osedax; however, marine birds have existed continuously since the Cretaceous and could thus have, in theory, provided an alternative food source for Osedax since that time.

References:
Potsherds of late Mesolithic/Neolithic age shed light on prehistoric ceramicist’s workshop

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Aims
The excavation site of Hamburg Boberg (northern Germany) is considered an important location for the documentation of the Neolithic Revolution (the transition from the hunter-gatherer’s way of live to the farming cultures) of Jutland peninsula, which comprises the mainland part of Denmark and parts of northern Germany. The Boberg area hosts pottery that covers artefacts of the late Mesolithic Ertebølle culture as well as the early to middle Neolithic Funnelbeaker culture. Moreover, there are numerous findings of sherd s that exhibit a foreign typology. By comparison of the manufacturing techniques, besides performing geochemical analyses of the clays, a distinction between a possible import history (by trade) and imitation of the foreign style by local ceramicists may be drawn. Here we document microstructural observations on selected potsherd samples that allow consideration of differences or similarities in manufacturing and firing processes by μ-CT based analysis of porosity distribution and analysis of the nature of the tempering agents (rock fragments, grog, organic compounds).

Method
For this case study we chose five potsherd samples from the excavation site of Hamburg Boberg (northern Germany). The samples (131-05, 138-67, 13-137, 15-93, 137-27) were scanned using the SkyScan 1172 device of the experimental and theoretical petrology group at Kiel University with a beam energy of 100 kV, a flux of 100 µA and a copper-aluminum filter with a resolution of 17.3 µm, performing a 360-degree rotation with a step size of 0.4 degrees in the oversized scan mode (3 connected scans). Image analysis and volume rendering was done using the SkyScan software CTAn, CTvol and CTvox.

Results
In the last decade, quantitative analytical methods (age dating, mineralogical and geochemical composition analyses) became widespread in the archaeological research community. However, besides the knowledge about age and provenance of raw materials, the most distinct characteristics of ancient pottery are imposed by the manufacturers of the artefacts. The five selected samples of late Mesolithic/Neolithic pottery sherd s are typologically distinguishable in terms of style and decoration. Here, we want to demonstrate the excellent applicability of μ-CT for the investigation of prehistoric pottery.

The microtextural inspection of potsherds 131-05 (see Figs. 1A and 2A) and 13-137 (see Figs. 1C and 2C; both samples belong to the Funnelbeaker culture) reveals two prominent features: cavities in the clay body and a high abundance of temper, consisting of rock fragments of various size.
Figure 1. (A) to (E) Reconstructed images of Neolithic pottery fragments (potsherds) excavated from the northern German site Hamburg Boberg (samples 131-05, 138-67, 13-137, 15-93, 137-27). The samples show distinct differences in cavity morphology, in nature, preparation and abundance of tempering agents and in the character of the clay material. (F) and (G) Cavity morphologies reveal the use of organic tempering agents in the samples 138-67 and 137-27.
Figure 2. (A) to (E) Micro-CT-renderings of Neolithic pottery fragments. Visualization of the spatial distribution of temper (left), porosity (right) and potsherd morphology (middle left and middle right) in the samples 131-05, 138-67, 13-137, 15-93 and 137-27.
The cavities in these samples can be assigned to three different types: (I) elongated voids that propagate parallel to the sherd surface and terminate at the rock fragment temper (II) voids that surround parts of the temper and (III) cracks that are perpendicular to the surface and that reach - or emanate from - the sherd surface. Cavities of type (I) are very abundant, type (II) is frequent, and type (III) occurs in places. The rock fragment temper in the samples 131-05 and 13-137 shows angular to subangular sections in 2D and range from 0.3 to 4.5 mm in size. Moreover, sample 13-137 contains grog temper.

Sherd 138-67 (see Figs. 1B and 2B; presumably Funnelbeaker culture) exhibits all of the above mentioned cavity morphologies, although in quite different occurrences: voids of type (II) surrounding the rock fragment temper rarely occur, the sherd-parallel elongated voids of type (I) are less prevalent, whereas the cracks of type (III) are a common feature. Furthermore, the study of the cavity morphologies reveals a fourth type which is caused by the use of organic temper materials (type (IV), see Fig. 1F). As can be seen in Fig. 2B, Sample 138-67 shows a beautiful decoration.

Sample 15-93 (Figs. 1D and 2D) hosts types (I)-(III) of cavities mentioned. Because of the frequent use of grog temper, the type (II) cavities are a prominent feature. As in case of the rock fragment temper, cracks approaching the grog temper terminate. The grog causes a new type of porosity, type (V): voids inside the grog temper which seem to have various origins. Currently, the classification of 15-93 is not unambiguous.

Sample 137-27 (see Figs. 1E and 2E) is a worthy representative of the pottery of the vessels made by the late Mesolithic Ertebølle culture. The distinct appearance of the clay body devoid of rock temper or grog and the well-shaped style are striking. This sample holds neither cavities of type (I), (II) or (V). Cracks emanating from or reaching the sherd surface do occur. This artefact shows frequent occurrence of type (IV) porosity that documents the use of organic temper.

Abundance and nature of porosity and temper agents differ among the five samples (see Table 1). While similar in amount and nature of the temper (mainly rock fragments), sample 138-67 hosts very little porosity (1.4 Vol%). Although 138-67 possesses voids caused by organic temper, it contains less cavities in comparison to potsherds 131-05 (5.3 Vol%) and 13-137 (3.3 Vol%). The 5.2 Vol% porosity hosted by the grog-tempered sherd 15-93 exceed the 4.3 Vol% cavities in the vessel of the Ertebølle culture (sample 137-27). Moreover, the latter artefact contains the smallest portion of temper: it contains no solid aggregates and is stabilized only by the amount of organic temper that is preserved as voids after the burning process. In contrast, the potters that had manufactured the remaining samples obviously concerned the use of solid temper agents (rock fragments or grog) as essential component: samples 138-67 and 15-93 contain 9.3 Vol% and 10.6 Vol%, respectively, 13-137 hosts 13.0 Vol% solid temper material and 131-05 even 17.4 Vol%.

Amount and nature of temper agents as well as differences in the clay raw material may lead to divergent properties in the handling during the manufacturing process. Varied rigidity of the clay during the modelling process, differences concerning the firing temperature as well as differences in the shrinkage behaviour of the temper lead to divergent development of porosity in the pottery. Although containing highly varied amounts of porosity, the samples of the Funnelbeaker culture (131-05, 138-67 and 13-137) show notably similar frequency distributions of the pore size-classes.
Table 1. Abundance and nature of voids and tempering agents in Neolithic potsherds

<table>
<thead>
<tr>
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<th></th>
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</thead>
<tbody>
<tr>
<td>Total porosity (Vol%)</td>
<td></td>
<td>5.4</td>
<td>1.4</td>
<td>3.3</td>
<td>5.2</td>
<td>4.4</td>
</tr>
<tr>
<td>Closed porosity (Vol%)</td>
<td></td>
<td>1.7</td>
<td>0.9</td>
<td>1.7</td>
<td>1.2</td>
<td>1.8</td>
</tr>
<tr>
<td>Nature of voids</td>
<td></td>
<td>elongated voids in clay body, voids surrounding rock fragments</td>
<td>cracks and elongated voids in clay body, organic temper</td>
<td>elongated voids in clay body, voids surrounding rock fragments</td>
<td>elongated voids in clay body, voids surrounding rock fragments</td>
<td>cracks in clay body perpendicular to surface, organic temper</td>
</tr>
<tr>
<td>Solid temper (Vol%)</td>
<td></td>
<td>17.4</td>
<td>9.3</td>
<td>13.0</td>
<td>10.6</td>
<td>-</td>
</tr>
<tr>
<td>Tempering agents</td>
<td></td>
<td>rock fragments, organic</td>
<td>rock fragments, grog</td>
<td>rock fragments, grog</td>
<td>rock fragments, organic</td>
<td></td>
</tr>
</tbody>
</table>

* the characters refer to the allocation of the samples in Figs. 1 and 2.

* Cavities can be assigned into five types: (I) elongated voids that propagate parallel to the sherd surface and terminate at the rock fragment temper; (II) voids that surround parts of the temper; (III) cracks that are perpendicular to the surface and that reach - or emanate from - the sherd surface; (IV) cavities caused by the use of organic temper; (V) voids inside grog temper.

![Figure 3. Frequency distribution of different pore size classes contributing to the cavities in the Neolithic pottery fragments.](image-url)
(see Fig. 3) showing a peak at pore diameters around 100 µm. This may be induced primarily by the similarity of the temper used. Potsherd 15-93 hosts a significant fraction of porosity that is contributed by large cavities (exceeding 1000 microns) that are caused by the shrinkage behaviour of the grog temper. The extensive use of organic temper in the manufacture of Sherd 137-27 (Ertebølle culture) results in abundant pore diameters in the range of 100-500 µm.

**Conclusion**

The microstructure of selected prehistoric potsherd samples of the excavation site of Hamburg Boberg (northern Germany) has been investigated by X-ray microtomography. The samples show distinct differences in cavity morphology, in nature, preparation and abundance of tempering agents. The pronounced heterogeneity of prehistoric vessels requires a careful inspection of large parts of the ceramic microstructure. The nondestructive µ-CT method and its ability for computer-aided morphometric analyses is a powerful method for the quantification of textural distinctions. To further investigate similarities and differences in the manufacture of the various artefacts, we plan to characterise the clay raw material by investigation of the frequency variations of accessory heavy minerals and to perform morphometric analyses of size distribution and roundness of rock fragment and grog temper.
Segmentation of trabecular jaw bone on CBCT and µCT datasets

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Aims
The term bone quality is used often in a dentomaxillofacial context. It needs to be assessed prior to implant placement, or in the evaluation of disease processes. Nevertheless a clear definition of bone quality is lacking (Ribeiro-Rotta et al 2010). A quantitative evaluation can be done with histomorphometry. This evaluation, however, strongly depends on segmentation performance. The aim of this research was twofold: 1) to compare segmentation performance of 9 CBCT systems, using µCT images as the ground truth; 2) to compare morphometry using global and adaptive segmentation (Burghardt et al 2007).

Method
Four human formalin-fixed jaws including soft tissues were scanned with 9 different CBCT devices at clinical settings and with Skyscan 1173. The CBCT devices were 3D Accuitomo 80 (Morita, Japan), Galileos (Sirona, Germany), I-Cat (ISI, USA), Illuma (3M, USA), Newtom (QR, Italy), Picasso-trio (E-Woo, Korea), Promax 3D (Planmeca, Finland), 3D Scanora (Soredex, Finland), Skyview (MyRay, Italy).
Registration was performed in a Maximum Mutual Information sense, which is fully automatic and well suited for dental CBCT datasets, of which the pixel (voxel) values have not yet been calibrated in a standardized manner. In this procedure, linear interpolation is applied when necessary. The computational streamline was implemented by C++ programming with the ITK software tool (www.itk.org) of the National Library of Medicine. Image sets from all scanners for each sample were co-registered under a universal voxel resolution of 0.2 x 0.2 x 0.2 mm³, which is assumedly sufficient for comparative quality evaluation.
In CT-analyser, a region of interest for each jaw was chosen. This region was selected to contain trabecular bone only and in a continuous way. Because of the pre-processing, the regions for all scans were identical. The regions of interest were segmented for each scan, first using global thresholding, second based on adaptive thresholding.
All binary images were then analyzed for the following morphological 3D parameters: %BV, BS, iS, TbTh, TbSp and TbN. For each of the devices, these morphological parameters were compared to the parameters extracted from the µCT images. Furthermore, overlap between the VOI of all CBCT images and the VOI on µCT was calculated.

Results
Based on the mean morphometry results for each scanner over the different regions of interest, the overall percentage error was calculated, compared to the Skyscan results. This overall error, together with the percentage error in overlap, is shown in table 1.
Table 1: Overall percentage error and overlap error for CBCT vs. µCT using global thresholding.

<table>
<thead>
<tr>
<th>Device</th>
<th>Overall %error</th>
<th>Overlap %error</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accuitomo</td>
<td>35.9</td>
<td>29.3</td>
</tr>
<tr>
<td>Galileos</td>
<td>30.7</td>
<td>26.6</td>
</tr>
<tr>
<td>i-Cat</td>
<td>37.4</td>
<td>29.5</td>
</tr>
<tr>
<td>Illuma</td>
<td>44.7</td>
<td>33.7</td>
</tr>
<tr>
<td>Newtom</td>
<td>39.6</td>
<td>30.0</td>
</tr>
<tr>
<td>Picasso</td>
<td>30.2</td>
<td>23.8</td>
</tr>
<tr>
<td>Promax</td>
<td>39.1</td>
<td>35.1</td>
</tr>
<tr>
<td>Scanora</td>
<td>11.9</td>
<td>24.2</td>
</tr>
<tr>
<td>Skyview</td>
<td>74.8</td>
<td>39.0</td>
</tr>
</tbody>
</table>

We compared the percentage error from the ground truth (Skyscan) for global and adaptive segmentation. The result is shown in table 2.

Table 2: Overall percentage error for CBCT vs. µCT using global and adaptive thresholding.

<table>
<thead>
<tr>
<th>Device</th>
<th>Rms error</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Global</td>
</tr>
<tr>
<td>Accuitomo</td>
<td>30.0</td>
</tr>
<tr>
<td>Galileos</td>
<td>75.1</td>
</tr>
<tr>
<td>i-Cat</td>
<td>77.7</td>
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<tr>
<td>Illuma</td>
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<td>Newtom</td>
<td>39.2</td>
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<td>Picasso</td>
<td>81.2</td>
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<tr>
<td>Promax</td>
<td>81.4</td>
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<tr>
<td>Scanora</td>
<td>86.0</td>
</tr>
<tr>
<td>Skyview</td>
<td>73.1</td>
</tr>
</tbody>
</table>

Based on the overlap results from the adaptive thresholding technique, we constructed the following graph (Figure 1).

As such, a classification of CBCT scanner performance could be made. This classification could be compared to the subjective perception of the images. Below, 2 examples of a well and less performing CBCT device are depicted (Figure 2).
Figure 2: Good segmentation ability (L) and worse segmentation ability (R), as calculated by overlap

Conclusions
We have analyzed and compared the trabecular structure of several skulls scanned with dental CBCT, using µCT images as the ground truth. As such, we were able to quantify the segmentation accuracy of the different devices under evaluation. We found the parameter of overlap to be the most robust parameter to compare devices. This parameter was least influenced by the choice of threshold value for bone.
In the comparison of global and adaptive thresholding, we found the adaptive technique to be less sensitive to the threshold value. In addition, the adaptive technique resulted in segmentations closer to the ground truth. Therefore, we concluded that adaptive thresholding was a large improvement over global thresholding in jaw bone images made with dental CBCT.
Based on the overlap of CBCT images with µCT images, a ranking could be made between the scanners, that had great similarity with the intuitive classification of an observer. In a later stage, this intuitive classification will be compared in a systematic manner to the quantitative analysis through CT-analyser.

References:
Micro-computed tomography for imaging and quantification of non-mineralized tissues in rat mandibular condyle.

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Aims
Non-mineralized tissues are difficult of visualize and quantify. They could be normal anatomical structures such as blood vessels, or pathological lesions such as bone necrosis. Traditional techniques to examine non-mineralized tissues include histological analysis, which are limited to small areas of tissue and cannot provide adequate three-dimensional visualization and quantification (1-2). The aim of this study is to describe a simple method for visualization and quantification of non-mineralized tissues using micro-computed tomography (micro-CT).

Method
Rats used as controls for avascular necrosis associated with glucocorticoid administration in mandibular condyles were euthanized. Mandibular condyle articulates with the maxilla and skull by the temporomandibular joint below the zygomatic arch (Figure 1). Condyles were removed, cleaned of soft tissue, fixed overnight at 4°C in 4% paraformaldehyde, rinsed thoroughly in three changes of sterile phosphate buffered saline (PBS) and stored at 4°C while waiting for micro-CT scanning (Skyscan 1172, Kontich, Belgium with a 1.3MP camera) housed in the McGill Institute for Advanced Materials (MIAM). Acquisition of high resolution 2D images and reconstruction was performed using Control software for Skyscan 1172. Parameters for thresholding and analysis were selected using CTan software designed for quantification of bone microarchitecture. The region of interest (ROI) was drawn manually (Figure 2b). Thresholding for bone analysis was performed visually and selected at 70-255 range to mimic bone as closely as possible when compared to the raw image (Figure 2c, upper image). For non-mineralized tissues, the thresholding parameters were reversed (Figure 2c, lower image). Final adaptation of the ROI was achieved using the ROI shrink-wrap function (Figure 2d). Total and fraction of volume were calculated for bone and non-mineralized tissues.

Results
The results of the total and fraction of volume are tabulated below.

<table>
<thead>
<tr>
<th></th>
<th>Total volume (µm³)</th>
<th>Volume fraction (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bone tissues</td>
<td>3.963</td>
<td>92.973</td>
</tr>
<tr>
<td>Non-mineralized tissues</td>
<td>0.102</td>
<td>2.394</td>
</tr>
</tbody>
</table>
Conclusion
Visualization and quantification of non-mineralized tissues is possible using micro-CT.

Figure 1: Rat skull showing: nasal (N), frontal (F), parietal (P), occipital (O), zygomatic arch (Z), audital bulla (B), Maxillary (upper jaw) (Mx), premaxillary (PMx), incisors (I), upper and lower molars (M), coronoid process (CP), mandibular condyle (CD) and mandibular angle (A).

Figure 2: (a) raw cross sectional image of the mandibular condyle, (b) ROI drawn manually, (c) Thresholding for bone analysis (upper image) and reversed thresholding for non-mineralized tissues analysis (lower image), (d) Final ROI using shrink-wrap function, (e) image inside ROI.

References
Visualization of mouse and human femur based on SkyScan-µCT

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Aims
Due to its crucial role in locomotion, the trabecular architecture of femoral head and neck is a widely investigated subject in human and non human mammals¹,². The purpose of this study is a refined analysis of the alignment of mouse and human trabecular structure by refined 3D-visualization methods based on µCT-images.

Method
A preparation of a dry human femur placed at disposal by Simpleware Ltd., Exeter, UK, was scanned using a µCT scanner (Skyscan 1173, Skyscan, Belgium) with a resolution of 54.04 µm in all three spatial directions. A dried mouse femur was placed at disposal by Skyscan NV and scanned using a µCT scanner (Skyscan 1172) with a resolution of 6.78 µm in all three directions. All scanning was performed at Skyscan NV, Kontich, Belgium. Both image stacks were delivered as bmp- respectively as tiff-files with grey values ranging from 0-255.

For the sake of refined insight to the internal structure, the µCT-data of both preparations were subjected to direct volume rendering with high transparency using a logarithmic physical color map (dark blue/low– light blue – green – yellow – orange – red/high). For image processing and visualization, we used the visualization toolbox Amira 5.2.2³,⁴, Visage Imaging GmbH, Berlin, Germany.

Results
For the human femur, the typical trabecular arrangement often discussed in standard orthopedic literature⁵ can be observed (Fig. 1, 2).

Figure 1: Visualization based on the human femur preparation as a whole with the colors referring to the gray values of the µCT-data
A highly transparent visualization of the mouse femur as a whole is given in Figure 3, whereas, in Figure 4, some details of trabecular structure are displayed. According to different loading regimes of mouse and human locomotion, trabecular architecture is highly different.

**Conclusion**

3D-visualization based on μCT images enables detailed analysis of trabecular architecture of femoral head and neck of different mammalian bones.

**Acknowledgments**

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References:


Creation of Computational Model of Cancellous bone

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Aims

The paper deals with a creation of computational model of cancellous bone. Cancellous bone is inner porous part of bones and it is of a very complex geometry. It is composed of special trabecular architecture and the trabeculae can be less than 1 mm in diameter. In most cases, cancellous bone is modeled as a “non-trabecular” solid body with an apparent Young’s modulus. A creation of a “trabecular” model of cancellous bone (which, in our opinion, is more appropriate) is quite difficult. MicroCT images are necessary for this case as well as the software for their processing. However, other way how to obtain information about bone architecture is to mill thin layers out of the bone specimen embedded into dyed epoxy resin. Authors of this paper developed for this purpose specialized software called STL Model Creator¹ which works in Matlab platform. The software uses image processing methods in segmentation of cancellous bone images. The paper introduces a method of creating of computational model and initial stress-strain analysis utilizing this model is presented as well.

Method

Firstly, bone specimen was placed in 30% peroxide solution in order to remove any remaining impurities. Secondly, the specimen was embedded into hard epoxy resin which was combined with fine black dry powder from printer toner cartridges. The embedded bone specimen was then placed into vacuum pump and the air was pumped out. The resulting vacuum ensured penetration of epoxy into holes among trabeculae. Afterwards, thin layers (0.02 mm) were removing in sequence by using fine milling and images of each layer were taking. Prior to taking images by camera fixed on the milling machine and equipped with yellow filter the specimen was floodlighted by UV-light. From the obtained images polygonized mesh was created by using STL Model Creator software and the final mesh was saved in STL-file format. Subsequent analyzing of mechanical response of cancellous bone tissue to external loading can be performed by means of computational modeling, specifically by using numerical methods. The most popular numerical method – finite element method (FEM) – was used; specifically, commercial product based on this method - ANSYS 11.0 (Ansys Inc., Canonsburg, PA, USA). In general, computational model consists of four submodels: model of geometry, model of material, model of loads and model of boundary conditions.

At micro-level, cancellous bone is of the same mechanical properties as cortical bone². The material used in the computational model is homogenous, isotropic and linearly elastic – which is defined by two independent characteristics: Young’s modulus $E = 13700$ MPa and Poisson’s number $\mu = 0.3^3$. 

Figure 1: Geometry mode and E model of cancellous bone
The specimen was loaded in Z-axis by means of pre-defined displacements of all nodes at one side of the specimen in XY-plane.

Results
Using FEM one can identify risky locations of stresses and strains. Fig. 2 and 3 show typical first and third principal stress and strain distributions. These results indicate locations with the most severe tensile and compressive loading within individual trabeculae. In future, by using this methodology it will be possible to perform studies and analyses of mechanical interaction of bone with applied dental implants, bone substitutes etc. at higher modeling-level comprising detailed trabecular architecture.

![Figure 2: 1\textsuperscript{st} and 3\textsuperscript{rd} principal stresses [MPa] (0.5% elongation)](image1)

![Figure 3: 1\textsuperscript{st} and 3\textsuperscript{rd} principal stresses [MPa] (0.5% elongation)](image2)

Conclusion
The aim of this paper was to create a computational model of cancellous bone specimen reflecting the trabecular architecture. STL Model Creator software developed by the authors was used for the reconstruction of images obtained from sequential milling thin layers of the specimen. The computational model created this way belongs to models at the highest modeling-level used up-to-date.

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Structural characterisation of calcium alginate particles with TiO$_2$ photocatalyst

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Institute of chemical technology, Prague
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Aims
Photodecomposition properties of TiO$_2$ are usually used for decolourization and purification of water. The aim of this work is the preparation biocompatible particles with a TiO$_2$ photocatalyst which can be used for the purification of water.

Method
The aim of this work is the preparation biocompatible particles with a TiO$_2$ photocatalyst which can be used for the purification of water. These porous particles contain sub-micron TiO$_2$ anatase crystals dispersed in a calcium alginate hydrogel matrix. Preparation of these particles is very easy and cheap, but water radicals decompose not only pollutants but also the alginate matrix$^1$. Air- and freeze-drying techniques can significantly slow down the alginate decomposition rate. The influence of drying on the decomposition kinetics of calcium alginate/TiO$_2$ composite particles was investigated by gravimetry. Surface erosion and structure changes of alginate matrix with TiO$_2$ inclusions were investigated by SEM microscopy (JEOL JCM-5700 electron microscope) and SEM-hosted x-ray microtomography (SkyScan).

![Image](image.png)

(A) (B)

Figure 1: Structure of calcium alginate particle with (A) and without (B) TiO$_2$ anatase crystals. The image size is 1.8 (A) and 1.8 (B) mm.

References:
Quantitative 3D-Analysis of the Filler Dispersion using X-Ray Microtomography

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Aims
Plastic products do not only consist of pure polymers. In order to improve mechanical, chemical or optical properties a variety of fillers and additives are added to the polymer matrix. Typical examples include fibres, which can be applied to improve the mechanical properties, color pigments for colorization or flame retardants. Recently nano-composites, polymers with nano-particles as filler, have received a lot of attention. It has been shown that already small amounts of layered silicate nanofiller can considerably enhance the material properties of polymers [1-5]. For example, they can increase the elastic modulus without loss in impact strength as well as the resistance to thermal distortion. They improve tensile strength, fire behaviour and reduce gas permeability.

To achieve these improvements, a homogeneous dispersion of the layered silicate in the polymer is necessary. Layered silicate exhibits a strong tendency towards agglomeration. Therefore, producing nanocomposites without agglomerates is very demanding in terms of processing technology [1,3,5]. In order to optimise products and processes, the analysis of the dispersion of the filler is necessary. In most scientific publications microscopic methods leading to qualitative results of the clay dispersion are applied. Thus, it is difficult to compare the quality of the dispersion by microscopy, especially if the nanocomposites show a comparably homogeneous dispersion.

We present a method which implies 3D image acquisition using x-ray microtomography (micro-ct) and evaluation by a software-tool. This allows a quantitative 3D-analysis of the filler dispersion in comparably large sample volumes. Additionaly most methods of analysis require a special preparation of the samples. Only micro-ct requires no sample preparation at all and a complete granule can be scanned at once. Micro-ct-analysis can then reliably reveal remaining agglomerates.

Method
The ct-scans are performed with a Skyscan 1172 microtomography system (Skyscan N.V., Kontich, Belgium). Typical polymer granules have a diameter of ca. 5 mm. Therefore, no special sample preparation is necessary and the whole granule can be attached to the sample holder. In order to visualise even small agglomerates, the images are taken with the highest possible magnification leading to a nominal voxel size of ca. 1 µm³.

The algorithms for image analysis have been integrated into the software framework “Ozella3D”, which has been written in Matlab and C during this and previous projects [6,7]. The first step of the image analysis is the segmentation between polymer and nano-filler in the image data. Nano-clay is a mineral. It shows significantly higher x-ray absorption than the surrounding organic polymer matrix. Thus, a simple threshold segmentation algorithm can be applied [8].

In the next step, the labeling algorithm assigns a unique label number to connected areas marked as filler agglomerates. From the resulting label data the size distribution of the agglomerates can be calculated using standard blob-analysis methods [8].
Results
The application of this method for the analysis of nano-composites made from polypropylene and nano-clay is described in detail in reference [6]. Figure 1 displays a virtual cut through a typical sample. The agglomerates can be easily seen as white areas in the image. The method has proven to be a good alternative to the analysis of microscopic images. However, the approach also has certain drawbacks. Images recorded using micro-ct are nearly always being affected by noise and artifacts such as ring artifacts or beam hardening. Therefore, even by using the highest possible magnification only agglomerates larger than 20 µm in diameter should be considered for the analysis. The measured size distribution strongly depends on the threshold chosen for the segmentation between polymer and filler. Therefore, much care has to be taken for the development of standard routines for image acquisition, reconstruction and analysis of the data. Otherwise a fair comparison of the data is not possible.

![Virtual cut through a granule of a nano-composite made of polypropylene and nano-clay](image)

Figure 1: virtual cut through a granule of a nano-composite made of polypropylene and nano-clay

Conclusion
The dispersion of fillers has strong influence on the properties of the product. Many fillers exhibit a strong tendency towards agglomeration leading to reduced material properties. Therefore, detailed information about the filler distribution allows the improvement and optimisation of production processes and products. X-ray microtomography has proven to be a valuable utility for the three-dimensional analysis of the agglomerate size distribution of nano-composites. This method can be applied for all polymeric composites having a significant difference in x-ray absorption between filler and polymer matrix.

References:
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Using X-Ray Micro Tomography to assess the quality of Packaging Foil

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Aims
Unilever is a world-wide manufacturer of consumer goods. Many of our products require carefully designed packaging, to protect the goods during distribution, storage, sale, and use. Polymer foil is a semi-finished product used to produce tubs and lids in which products (like margarine) are stored. This material acts as a barrier against oxygen, water vapour, light, and dust.

The used polymer foils contain gas bubbles due to the use of foaming agents. The foaming agent forms gas, which is dissolved in the polymer, and expands in the extruder due to pressure drop. To enhance mechanical properties, certain fillers can be added (like talc and calcium carbonate).

A variety of destructive methods exist to assess the quality of polymers, yet X-Ray Micro Tomography would allow us to investigate the material in a non-destructive manner. The aim of this work was to investigate the usefulness of Micro-CT to identify the size, shape and distribution of the gas bubbles and to identify mineral fillers in the polymer matrix.

Method
Small samples were cut (approx. 2 x10 mm), from both the foil, and a tub produced from the same batch of foil (Fig.1). Next, the pieces were glued on a brass pin (Fig.2).

Fig.1: Foil and Tub Samples
The scanner model being used is the Skyscan1172, which allows scans with high spatial resolution with a smallest possible pixel size of less than 0.8 micron.

Since we wanted to perform the scans at the highest resolution, and the largest possible magnification, it was useful to mount the pins on the SkyScan micro stage (Fig.3). This clever device allows automatic adjustment of the center position of the sample while it rotates. This ensures that the sample stays in the field-of-view of the camera during the rotation. Precise object centring improves all aspects of scan quality.

To find optimal scan parameters, a small number of test-runs were carried out. Of special interest here are the choice of rotation step, and frame averaging. In general, if you scan low density materials and require high detail it is preferred to have a small step size. However, this generates more images, and together with a typical frame averaging value of 4, this leads to long scan times and extremely large datasets.

It was concluded that the following settings gave the best overall result:

<table>
<thead>
<tr>
<th>Scan Parameters</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Camera Resolution</td>
<td>4000x2096</td>
</tr>
<tr>
<td>Pixel Size</td>
<td>0.84 µm</td>
</tr>
<tr>
<td>Power</td>
<td>60 kV</td>
</tr>
<tr>
<td>Current</td>
<td>167 µA</td>
</tr>
<tr>
<td>Rotation Step</td>
<td>0.20</td>
</tr>
<tr>
<td>Frame averaging</td>
<td>2</td>
</tr>
<tr>
<td>Filter</td>
<td>None</td>
</tr>
</tbody>
</table>
Each scan will then take just under 2 hours and leads to a data set of around 1000 images, with a size of 15 Gigabytes. Characteristic examples of projection images are shown here after stretching the contrast (Fig.4 and 5) together with typical grey-level profiles (Fig.7 and 8). These were taken from an unstretched image by measuring a single line through the center with ImageJ software.

Fig.5: Projection image  
Semi-finished product (foil)  

Fig.6:  
Projection image  
Finished product (tub)  

Fig.7: Grey-level profile of a single projection image (foil)  

Fig.8: Grey-level profile of a single projection image (tub)  

The projection images were reconstructed using NRECON V1.6.3.2. The post-alignment parameter was automatically calculated and set to a value of -11.5. This indicates that although the scan was performed at high magnification, the foil was kept very well in its central position and almost no movement appeared.

Because the frame averaging during the scan was low, some smoothing was applied, which helps to reduces noise.
A single slice from the resulting stack of nearly 2000 images is as large as 4000x4000 pixels. That makes the whole stack almost 15 Gigabyte which is too large for processing effectively in image analysis software. Not even with today's powerful workstations. That’s why they are being resampled (2x under-sampling in 3D), and a region of interest (ROI) was taken with CTan software from SkyScan, resulting in a dataset of 979 slices of 1032x1520 pixels. Further processing, analyses and visualization on the images was carried out using Avizo 6 visualization software from Visualization Sciences Group. See the website from VSG for more information.

Since the resampled dataset was still large to process in a reasonable amount of time, a subset was taken (Lattice-Access) consisting of 150 slices of 400x400 pixels. Next, an edge-preserving smoothing filter was used (Fig. 9) to further reduce noise. This filter is similar to a Gaussian filter; it smooth’s out the difference between grey levels of neighbouring voxels. This can be interpreted as a diffusion process in which energy between voxels of high and low energy (grey value) is leveled. In contrast with the Gaussian filter, it does not smear out the edges because the diffusion is reduced or stopped in the vicinity of edges. Thus, edges are preserved.

The resulting images could be successfully segmented (Fig.10) using a threshold-value allowing further analyses. Also, after segmentation it is possible to create 3D surface renderings (Fig.11).
Results
Shown are example (horizontal) slices from the reconstructed set for the foil, and for a piece of the tub (Fig. 10). Note the difference in height of the pictures, which actually represents the thickness of the polymer, since you are looking at it from the top. The gas bubbles are clearly visible, and also some filler material (black spots) can be seen.

Fig.12: Horizontal or Transverse plane views (z)

Fig.13: Vertical or Coronal plane views (x)
It can also be revealed in which direction the material was pulled during the fabrication process. To see if the bubbles are distributed somewhat homogeneously a vertical view was created with T-view software from SkyScan (Fig. 13).

From the labeled data, simple statistics can be calculated like the total amount of bubbles. E.g. for the foil, it was calculated that it contained about 20 volume-percent of gas-bubbles.

A 3D rendered image exposes that the bubbles are not heavily interconnected. That is highly desired since no open canals may exist from the outside to the inside since that would make the packaging material unsuitable for its task. This is illustrated by the blue area in the rendered image, which are all bubbles connected with the outside world (Fig. 14). These penetrate the material only at the edges.

Fig. 14: 3D rendering of bubbles in a foil sample showing inside bubbles (yellow) and outside bubbles (blue) which are connected to the outside world.

To get an impression on how the filler material (black spots) is distributed in the foil, a 3D volume rendering was done on a stack of 100 slices (Fig. 15).
Conclusion
Micro-CT is an extremely useful technique to investigate the inner structure of a polymer. Using the SkyScan 1172 scanner it is possible to generate images with a pixel size as small as 0.8 µm.

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Computer aided customized creation of scaffolds

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Aims
The design of scaffolds and search for the optimal pore shape and size is a topic of ongoing research within the tissue engineering community. In a 2009 review paper Hollister¹ finds i) the need for a more complete understanding of scaffold material and design requirements and ii) the need to better integrate computational design techniques with manufacturing methods as two of the six main reasons why the penetration of new scaffolding materials and structures from research laboratories to the clinic has been extremely limited.

Method
This paper presents a method to obtain fully customized 3D computer scaffold designs starting from patient specific scan data. The resulting scaffolds are ready to be produced via rapid manufacturing techniques. This method is then illustrated on a mouse bone scaffold coming from micro-CT scan data acquired by the SkyScan 1076 system using Mimics Innovation Suite software as shown in figure 1. From the virtual design a 3D printed scaffold is created in polycaprolactone using a fused deposition modelling technique.

Results
From patient specific data a high quality 3D triangle mesh model is calculated. From this model the anatomy to be replaced by a scaffold is selected and virtually separated. A porous unit cell which can be designed by the user, also represented by a triangle mesh, is patterned into a geometry which envelopes the separated anatomy from above. A virtual cutting operation on triangle mesh level between the separated anatomy and the patterned grid results in a customized scaffold structure.

Figure 1: Workflow summary to obtain a customized bone scaffold starting from a micro-CT from a mouse.
Conclusion
The ability to create customized scaffolds with an unlimited freedom in unit cell structure can increase the speed of research and understanding of the influence of scaffold pore size and shape on cell differentiation and cell growth rate.

References:
Low level laser therapy effects on distraction osteogenesis obtained by x-ray computed microtomography

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Aims
Distraction osteogenesis (DO) is a technique of considerable capacity of bone regeneration in cases of bone deformities and defects. In this study, the aim is to comparatively evaluate both short and long term effects of low level laser therapy (LLLT), a procedure of well recognized positive effects on bone regeneration. Specimens were analyzed using histomorphometric, micro-tomographic and conventional radiographic methods.

Method
16 rabbits were included in the study and they were divided into two groups of early (28 days) and late (56 days) consolidation periods. Each group was also divided into two subgroups (4 rabbits in each group) one of which was applied LLLT (experiment group) while the other group received no additional treatments (control group). Following a period of 5-day latent period, unilaterally placed mandibular distractors were activated 1 mm per day for 6 days. Mandibles of rabbits in early and late term experimental groups were biostimulated using a GaA1As laser after the activation of distraction (0.25 W for 30 seconds from 6 different angles). Rabbits were sacrificed after the completion of consolidation periods on 28th and 56th days.

Specimens were analyzed using histomorphometric, micro-tomographic and conventional radiographic methods. Tomographic data were obtained using Skyscan (Belgium) 1174 compact micro-CT at Department of Anatomy in the Faculty of Medicine at Hacettepe University (Turkey). The bone samples were cut under serum bath to suitable sizes for the chamber of micro-CT. Bone samples were placed in perspex filled with formol (Figure 1). 50 kV X-ray source was used with a power of 40W. The bone samples were rotated at 1° steps over 360° rotation and their sinograms were acquired by a cooled 1.3 megapixel X-ray camera.

The distraction zones were drawn manually on CT-analyser, © Skyscan, Belgium. The open zone excluding the radiopaque bone was thresholded and the volume of radiopaque bone was calculated (Figure 2). The volume ratio of radiopaque zone in the distraction zone was used as statistical data.
Results
After micro-tomography analysis, ossification was observed in every group (Figure 3). All analyses revealed statistically significant results of laser application in the short term (28 days). As the result of the study; positive supportive effects of LLLT on distraction treatment including shortening the healing period and hindering possible risks and complications were experimentally indicated and reported.

Conclusion
X-ray computed micro-tomography (CMT), a non-destructive method providing three-dimensional data enabled the calculation of volumetric data for regenerated bone in the distraction zone. The usage of micro-tomography with supplementary methods such as histomorphometric and conventional radiographic methods will expand its usage in distraction osteogenesis (DO) studies.
3D X-ray Microtomography of Materials at AWE and Collaboration with the Royal Botanic Gardens Kew, Millennium Seed Bank

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Introduction
This paper highlights the wide range of materials to which AWE has applied 3D X-ray microtomography analysis and the information this has provided using a 100kV Skyscan 1172 instrument with a 10Mpixel camera. In each case our test and analysis methodologies have been detailed.

The paper will also highlight the results of collaboration with the Royal Botanic Gardens, Kew, Seed Conservation Department at the Millennium Seed Bank. The Skyscan 1172 was used to investigate the germination of seeds.

Materials and Test Methodology

1. 3D Internal Structure and Properties of Foamed Peroxide Cured Polysiloxane Rubber.
Experiments have been performed to evaluate the suitability of 3D X-ray microtomography for probing the microstructural characteristics of foamed polydimethylsiloxane rubber (M97) using a Skyscan 1172 instrument. The aim of this work was to determine if a gross property change could be obtained and used to compare the three types of foam, which has been achieved.

Samples were compressed using a Skyscan 50N tensile stage which was then scanned at 60kV X-ray energy. Porosity and total volume data was acquired along with mass and stress/strain data for the material. M97 prepared using two different sized urea cell formers 600µm and 300µm were evaluated. Two types of 300µm urea cell formers were used, 300µm prills and 600µm prills crushed and sieved to 300µm. The results showed significant differences in material property due to cell size and shape.

The density of each sample was calculated from the measured mass and the total volume as measured by the Skyscan software. The results show there is a close similarity in the density between full scale (600µm prills) and half scale (300µm prills) and both trends are very different to that of the half scale (crushed 300µm), see figure 1. The important observation
here is that the foam using the sieved 300µm prills was close to the density of the full scale material.

The comparison of porosity against density, see figure 2, shows that the foam generated using the crushed urea has a higher initial density while maintaining a higher porosity at the higher compression when compared to the full scale and half scale urea prills both of whose properties were again very similar.

Figure 3 shows that the porosity values for the three foams overlap between 30% to 35% compression, again showing the crushed urea pad had a higher porosity beyond 35% compression.

The stress strain curves in figure 4 show that the foam generated using the crushed urea was much softer than either of the foams made using full scale or half-scale prills. The maximum stress for the sieved and crushed prilled foams was approximately the same, whilst the full scale foam was considerably higher. It is believed this is due to the difference in material thickness. The half-scale sieved prilled foam followed closely the stress/strain curve for the full scale foam indicating it has similar mechanical properties.

Figure 5 shows the difference in structure from using sieved or crushed prills at 0, 30 and 50 % compression. The foam produced using crushed urea had irregular shaped cells compared to full scale and sieved prilled foam.

Overall, the combination of 3D X-ray tomography with the compression stage has enabled the differentiation of the three types of foam based on porosity and nominal density measurements non-destructively.

2. Finite Element Analysis

Finite Element Analysis modelling is important for life assessment studies of components in many industries. Rapid prototyping and micro moulding now require modelling at the micron scale. The 2D slice data from the M97 image sets was converted to LS-DYNA mesh using Simpleware™ Scan IP and Scan FE software, the software has many FE output options. This now allows FE analysis of foamed materials at the micron scale. Figure 6 shows a typical finite element mesh for the LS-DYNA analyser.

3. Rigid Polyurethane Foam

X-ray tomography highlighted the change in morphology for a polyurethane resin foamed in a constrained (mould tool) and unconstrained (measuring cylinder). The constrained sample had a closed cell structure while the unconstrained sample had an open cell structure. Porosity of the open cell was 46 to 64 % and for the closed cell 23%. Figure 7 (a) and (b) show the differences in structure between the two foaming methods.

4. Diffusion Limited Oxidation

Metal hydride’s grow a oxide and hydroxide layers when exposed to air. Skyscan software was able to measure the thickness of layers in the object. This limited study indicated the oxide and hydroxide layers reached a diffusion controlled rate. Figure 8 (a) shows the freshly cut sample and figure 8 (b) shows the growth of the surface layer after 6 days. The observation of importance is graded growth of oxide at the freshly exposed surface. The oxide and hydroxide layers exposed to the air prior to the fresh surface being made are virtually unchanged.
5. Composites.
3D X-ray tomography has been used to assess the difference between different types of fibre phenolic resin composites. The structure of the carbon fibre composite figure 9 (a) could not be resolved because of the similarity in density of the fibre to the resin. What can be seen however is the damage caused by plasma ablation tests as shown in figure 9 (b). Figure 9 (c) shows a quartz phenolic resin composite for comparison.

Nylon granules were bonded using a selective laser melting system using an EOS P730 machine at three different scan speeds 1000, 2000 and 5000 mm/s. The object of this study was to assess whether scan speed would make any difference to the porosity of the material. Repeat samples showed there was a spread in the porosity distribution from 6% to 16%. Scan speed appeared to have little effect. Figure 10 shows images of the nylon produced.

7. Target Fabrication
Additive manufactured laser target using metal alloy by Electro Optical Systems was characterised by 3D X-ray CT. This allowed the micro structure of the additive manufactured target to be assessed for quality assurance indicating problems with voids and over hangs in the fabricated sample, see figure 11.

8. Aerogel for Laser Target
3D-CT of a gold loaded aerogel in a 1mm diameter tube showed whether the tube was filled. This was useful for quality control purposes with figure 12 (a) showing a good fill at mid height in the tube but shrinkage towards the top, shown in figure 12 (b).

9. Imaging of Jubaea chilensis Germination
Jubaea chilensis is the only living species in the genus Jubaea in the palm family Arecaceae. It is native to southwestern South America, where it is endemic to a small area of central Chile, principally the regions of southern Coquimbo, northern Maule, O'Higgins, Santiago and Valparaiso.

Jubaea chilensis is the world's tallest indoor plant housed in the Palm House at the Royal Botanic Gardens, Kew.

The objective of this aspect of the work was to track the development of the seed embryo as it forms the haustorium, a body that consumes the endosperm providing hydrostatic force for the root to break out of the endocarp (seed coat) and nutrients for the developing root and leaves.

Seed Preparation
• The hard endocarp (shell) is cracked open and the endosperm containing the embryo is removed. The endosperm has a brown outer skin.
• The endosperm was placed in a container with nutrient agar gel and kept at 30ºC in incubator. Later samples grown in Perlite medium.
• Light regime 12 hours on/12 hours off.
• The root and leaf were trimmed prior to imaging to fit in to the sample chamber.

Imaging of Germination
Germinating seeds at different stages of development, see figures 13 (a) and 13 (b),were imaged at 16µm to 17.5µm per pixel resolution using the 2000 x 1048 pixel camera. X-ray energy ranged from 60 to 100 kV depending on sample density. Figure 14 shows the structure of Jubaea chilensis seed highlighting the embryo, endosperm and endocarp (seed
coat). Figure 15 shows the embryo growing and spreading tendrils into the endosperm to
extract nutrients and fluid for pushing through the endocarp and forming a root structure.
Figure 16 shows the development of the embryo into the haustorium a sponge like structure.
Figure 17 shows the final stage of the haustorium breaking down the endosperm, at this
stage the root structure will be supplying nutrients.

10. Daemonorops sabut
Palm Oil seeds have a hard outer seed coat that is difficult to microtome for conventional
sectioning and microscopy. 3D X-ray microtomography allows the internal structures of the
seed to be observed without damaging the seed. Figure 18 below shows the internal air
voids within the seed.

Conclusion
3D X-ray microtomography has been successfully used for the analysis of a wide variety of
materials. For foamed objects gross changes in cellular structure can be easily analysed for
porosity and volume.

The ability to convert 2D slice data sets into 3D finite element mesh supports the capability to
model materials at the micrometre level facilitating FEA development.

3D-CT has proven useful in supporting research into the changing properties of materials
through time and temperature.

Further development of 3D-CT is required for phase contrast imaging and morphology
measurements especially for quantifying open to closed cell volumes for foams.

3D X-ray microtomography has proven a useful technique to investigate the growth of plant
seeds.

A variety of seeds have been imaged and additive manufactured models presented to Kew
Gardens Millennium Seed bank for public display.

Acknowledgements
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Wakehurst Place, West Sussex
Figure 1 Bulk density as a function of compression for polysiloxane foam

Figure 2 Porosity as a function of density
Figure 3 Porosity as a function of compression

Figure 4 Stress as a function of strain

Figure 5 Comparison of foam structure at different compression
Figure 6 LS-DYNA mesh of polysiloxane foam

Figure 7 (a) Coronal image of unconstrained foam (15µm/pixel)

Figure 7 (b) Coronal image of constrained foam (8µm/pixel)
Figure 8 (a) Fresh cut surface of metal hydride

Figure 8 (b) Oxide/hydroxide layer growth after 6 days
Figure 9 (a) Carbon fibre composite before ablation

Figure 9 (b) Carbon composite after ablation

Figure 9 (c) Quartz fibre composite

Figure 10 CT images of additive manufactured nylon at different laser scan speeds
Defects can be seen in the target where the powder has not sintered.

Figure 11 3D image generated using VG StudioMax2.

Figure 12 (a) Good fill at mid section

Figure 12 (b) Shrinkage at top of tube
Figure 13(a) Embryo/root 4mm

Figure 13 (b) Root 120mm / Stem 110mm

Figure 14 False colour image of seed highlighting seed structure.

- Hard seed coat (endocarp). Images shown in false colour to highlight density differences.
- Endosperm
- Embryo, separate entity within the endosperm
Figure 15 Development of embryo at 8mm root length

Figure 16 Image shows the development of the haustorium
Figure 17 Final stage of haustorium breaking down the endosperm

Haustorium has filled the cell and is breaking down the endosperm

Figure 18 Internal air voids within a seed of Daemonorops sabut
Structure Characterisation of Catalysts

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Aims
Catalysts are commonly used not only in process industries but also in everyday life. Generally, catalysts are used to accelerate chemical reaction rates. Catalysts consist of porous material, which acts as a support for the active component. A classification is used according to the pore diameter: macropores (>50 nm), mesopores (2 - 50 nm) and micropores (<2 nm).

Attention is needed in optimising catalytic materials through methods of preparation to obtain the desired porosity and strength. To determine the internal structure of selected catalysts, X-ray micro-computed tomography and other complementary methods (such as Scanning Electron Microscopy and mercury porosimetry) are used (Farber et al., 2003). Some techniques (such as mercury porosimetry) are already used to measure the pore size distribution within catalysts (Rigby et al., 2003). Therefore, X-ray micro-computed tomography will provide further information on the density variation, the distribution and shape of the pores and/or cracks. It will also reveal the interconnecting passageways that influence permeability and control the flow of fluids, by using 3D analysis (Atwood et al., 2004; Rigby et al., 2008).

Method
The materials studied were 3 mm in diameter catalyst tablets. The samples were scanned using two different systems: the Skyscan 1072 and the Skyscan 1172 desktop micro-CT. The maximum resolution was respectively 2 µm and 0.8 µm.

For every sample, the system was set to a voltage of 101 KW and a current of 98 µA. X-ray images were acquired from 200 rotational views through 180° of rotation (0.9° increments) and 2 frames for each rotation step. An aluminum filter was used.

The raw data acquired were reconstructed using N-Recon Software (ver. 1.6.3). Image analysis of the reconstructed images was carried out using CT Analyser (ver. 1.10.0.1) which allows 2D and 3D analysis of images. CTvol (ver. 2.1.1.0) and Data Viewer (ver. 1.4.2.2) were also used.

Results
A catalyst sample was analysed using the Skyscan 1072 and Skyscan 1172 systems. In both systems, images revealed information on the internal structure network, the void space (e.g. pores and/or failures) and the densities of the samples. However, the resolution was not good enough to determine the detailed information on the porosity using these measurements as the pore size of the sample is below 50 nm (Rigby et al., 2003).

The same sample was analysed using the Skyscan 1172. As a result of the better resolution of the system, more detailed information was obtained. Indeed, macropores, with a minimum of 2 µm diameter, were identified. The comparison of the grey level distribution for both systems has been made. When compared to the 1072 system, the percentage frequency for the 1172 system increased. In addition, the mean value distribution of the 1172 system was lower than the 1072 one. These results indicate that the newer system revealed more information, which might be useful for further image processing.
In figure 1, the reconstructed image from the Skyscan 1172 showed the presence of a ring artifact. Moreover, the thin layer of beam hardening artifact present on the surface using the Skyscan 1072 has disappeared when using the Skyscan 1172 system.

**Conclusion**

X-Ray micro-CT and bundled software from Skyscan seems to be a powerful and promising tool in analysing the microstructure of catalyst samples. The Skyscan 1072 and 1172 systems reveal information on the internal structure network, the void space (e.g. pores and/or failures) and the densities of the samples. However, care is needed for the image processing in order to study density. At the moment, the results, the effect of noise and the ring artefact on images are under investigation.
References:
Poikilitic heterogeneity of mixed crystals

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Aims
The work is dedicated to investigating so called poikilitic crystals consisted of a monocrystal matrix saturated by small crystal inclusions. The specificity of analyzed crystals belonging to a continuous isomorphic series is implanting inclusions into initially solid crystal during its isomorphic replacement in polycomponent solution. The implanted inclusions compensate volume deficit of the replaced crystal in comparison with the initial crystal. We forecasted such a process, observed it in situ for the first time in model salt-aqueous systems by means of optical microscope, and interpreted it comprehensively [1, 2]. It is necessary to note that formation of poikilitic crystals was connected recently with growth together only.

Method
Experimental obtaining of poikilitic crystals were carried out in the polycomponent system CoSO₄·FeSO₄·(NH₄)₂SO₄·H₂O, which includes fields of isomorphic series (Fe, Co)SO₄·7H₂O and (Fe, Co)(NH₄)₂(SO₄)·6H₂O. Monocrystals CoSO₄·7H₂O (around 10 mm) interacted with eutonic solution FeSO₄·7H₂O·(NH₄)₂SO₄·H₂O (around 50 ml) at room temperature. Obtained samples of around 5x5x10 mm in sizes were measured by means of microtomograph Skyscan 1172. We needed an immediate scanning because of quick dehydration was the specific feature of the substances. The tomographic data were compared with pictures obtained by means of optical microscopy when thin crystal sections of CoSO₄·7H₂O (up to 0.5 mm) were placed with a solution droplet between parallel glasses.

Results
Poikilitic samples obtained contain crystal matrix of (Co, Fe)SO₄·7H₂O in composition and numerous crystal inclusions (NH₄)₂(Co, Fe)(SO₄)·6H₂O as well as liquid inclusions of mother solution and air pores lost solution (Fig. 1). Inclusion sizes range in sizes up to tenths of millimeter and disperse irregularly in the matrix body. Some tendency appears in zonal distribution of inclusions, replicating irregular contour of the initial crystal.

Fig. 1. Inclusions in the matrix body: poikilitic, liquid and air (bluish, reddish, and black spots respectively). Crystal size is 5 mm.
Tomographic images allow to give optical observations in detail. Optical images (Fig. 2) are similar to tomographic ones as a whole. It is seen in particular that solid inclusions implanted into the matrix spread chaotically over the poikilitic crystal volume. However a comparatively big thickness of optic samples causes overlapping inclusions of different levels. Therefore it is not easy to characterize their distribution; moreover the images are not clear, that is why the shapes of individual inclusions as well as relationships between neighbor inclusions and their interaction with the matrix are indeterminable.

The results of microtomographic and optic observations cause following conclusions. A synthesized poikilitic sample consists of monocrystal (Fe,Co)SO₄7H₂O-matrix saturated by small foreign (Fe,Co)(NH₄)₂(SO₄)₂6H₂O-crystals and liquid inclusions of the mother solution. Crystal of the initial composition CoSO₄7H₂O is gradually enriched with isomorphic component FeSO₄7H₂O by means of multiple local dissolution of different unstable surface micro-spots and next re-precipitation of a stable solid solution (Fe,Co)SO₄7H₂O on adjacent micro-spots. This reaction runs with volume deficit. Implanted inclusions of mother solution compensate the deficit, while (Fe,Co)(NH₄)₂(SO₄)₂6H₂O-microcrystals precipitate from the solution in the inclusions immediately.

![Fig. 2. Poikilitic inclusions within monocrystal matrix. Microphoto.](image)

**Conclusion**

Tomographic investigations of poikilitic crystals combined with optic observations allows certain determining laws of formation process for such structures. It is obvious that difficulties in image interpretation can arrive if densities of matrix and inclusions are similar.

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**References:**

Inhomogeneity of mixed crystal formed from aqueous solutions: studding by mCT

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Aims
We investigated mixed crystals inhomogeneity undergone isomorphic replacement and direct
growth in aqueous solutions. Most of minerals and industrial substances are represented by
isomorphic-mixed crystals, which formation is characterized by specific phenomena and
mechanisms distinguished substantially from those for crystals with fixed composition [1].

Method
Mixed crystals (Mg,Ni)SO4·7H2O, (Pb,Ba)(NO3)2, and K(Cl,Br) were obtained by either
isomorphic replacement of initial pure crystals or spontaneous growth as it is indicated in the
caption to Fig. 1. The obtained crystals were investigated experimentally ex situ by means of
X-ray micro-tomography (SkyScan 1072 and 1172). Crystal replacement in the series
(Mg,Ni)SO4·7H2O was also observed in situ. Crystal sizes are around 5x5x2 mm.

Results
In the case of replacement initial crystals keeping the monocrystallinity are either coated by
epitaxial excrescences of a mixed composition (Fig. 1a) or saturated by numerous implanted
inclusions (Fig. 1b, 2). Cross-sections show different inhomogeneities of crystals (Fig. 1 –
various colors), which were confirmed by means of X-ray diffractometry and microprobe
analysis. The relic of Ba(NO3)2-crystal is more or less homogeneous but excrescences have
intermediate composition of the series (Ba,Pb)(NO3)2 (Fig. 1a). The MgSO4·7H2O-crystal
completely replaced by (Mg,Ni)SO4·7H2O (Fig. 1b) contains secondary fluid inclusions (dried
during keeping) and zones of different total compositions formed at different experimental
stages. The grown K(Cl,Br)-crystal is composed of mosaic texture, which is formed by
domains up to 10-15 mkm in sizes (Fig. 1c). Colors indicate variations of isomorphic
components ratios and show total zoning and local heterogeneity while domains are mutually
coherent.

Steps of MgSO4·7H2O-crystal transformation in the course of isomorphic replacement during
interaction with NiSO4·7H2O-solution are displayed in Fig. 2. The images were obtained by in
situ scanning at SkyScan 1072. Scanning in solution caused a diffusiveness of the Fig. 2b,c.
The replaced rim is relatively dark in Fig. 2b, the non-replacement core is more light. At the
end of experiment (18 hours later) the crystal is replaced totally (Fig.2c). The crystal
boundary became tortuous due to solution heating caused dissolution.
Fig. 1. Monocrystals undergone isomorphic replacement (a, b; top – 3D, bottom – cross-sections) and direct growth (c). Scanning ex situ. a – (Ba,Pb)(NO$_3$)$_2$ formed by interaction of Ba(NO$_3$)$_2$-crystal with Pb(NO$_3$)$_2$-solution; b – (Mg,Ni)SO$_4$·7H$_2$O formed by interaction of MgSO$_4$·7H$_2$O-crystal with NiSO$_4$·7H$_2$O-solution and the following interaction of obtained (Mg,Ni)SO$_4$·7H$_2$O-crystal with MgSO$_4$·7H$_2$O-solution; c – inhomogeneous distribution of isomorphic components in K(Cl,Br)-crystal formed from solution with component molar ratio KBr/KCl=2/1.

Fig. 2. Steps of monocrystal isomorphic replacement MgSO$_4$·7H$_2$O-crystal in NiSO$_4$·7H$_2$O-solution. Scanning in situ. View of the crystal before interaction (a), after 1 h (b), and after 18 h (c).

Conclusion
Mixed crystals formed in solution by different processes are inhomogeneous in composition. A mosaic character of mixed crystals we revealed for the first time is a principal importance for the knowledge on the growth specificity of such crystals. Growth front and adjacent solution layer have a coordinated heterogeneity which is of an extended lifetime. Therefore such inhomogeneity appears to be the immanent feature of mixed crystals [2]. This should be urgently taken into account at reconstructions of the mineral origin and at growing of such crystals.

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References:
Multiscale visualization of biomaterials based on SkyScan-µCT

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Aims
We present a µCT-based 3D-visualization approach suitable for (bio-) materials composed of several constituents characterized by different scales, e. g. macro-porous scaffolds doped with some material characterized by meso- or micro-porosity. Exemplarily, we analyze a macro-porous Al₂O₃-ceramic sample with a micro-porous apatite coating. The corresponding double-porous structure is at the focus of our investigation.

Method
Al₂O₃ is a very stable and inert bio-ceramic¹. We analyzed a cylindrical sample with diameter of about 4.5 mm and height of about 2.5 mm. For testing purposes of the behavior of the alumina in a physiological solution, the specimen was immersed in phosphate buffered saline (PBS). As a result, the surfaces of the macro-pores of the alumina scaffold were coated by micro-porous apatite-like layers. The sample was axially scanned with a µCT scanner (Skyscan 1172, Skyscan, Belgium) at a resolution of 6 µm in all three spatial dimensions. The images were delivered as bmp-files with grey values ranging from 0-255 (Fig. 1). The manufacturing, the preparation, and the scanning of the sample were performed at the Faculty of Materials Science and Engineering, Warsaw University of Technology, Warsaw, Poland.

For the sake of a first overview, we visualized the sample as a whole by maximum intensity projection at reduced resolution (Fig. 2).

Based on recent approaches²,³, the grey values of (micro-) CT data can be translated into chemical composition of the investigated tissue, namely the volume fractions of the single constituents within the considered voxel. The investigated sample consists of three major constituents, namely the “primary” alumina matrix characterized by high contrast, the “secondary” apatite like coating material, and the macro-pores.

Thereon based, we performed a “double” direct volume rendering approach with different transfer functions, a first one with emphasis on the alumina matrix, and a second one for the coating material. For the alumina matrix, we chose a logarithmic transfer function based on a grey scale. For the coating material, we also referred to a logarithmic, but highly lucent two-tone transfer function.

We performed the visualization at three different levels of detail, firstly, the sample as a whole at reduced resolution (Fig. 3), secondly, a segment of the cylinder at original resolution (Fig. 4), and thirdly, a detail analysis of a small section of 700 µm x 700 µm x 700 µm for the analysis of the micro-pores within the coating material (Fig. 7-9). For the latter, we subjected the extracted section to resampling to a resolution of 2 µm in all three spatial dimensions.
using a Lanczos algorithm (Fig. 5, 6). We performed measurements of the pores of the alumina, as well as of the micro-pores of the coating material.

As a variant for convenient illustration, stereo visualization based on anaglyph or anachrome\textsuperscript{4} imaging and animated movies gained high acceptance by many users. For all image processing, programming, and visualization steps, we used the visualization platform Amira 5.2.2\textsuperscript{5,6}, Visage Imaging GmbH, Berlin, Germany.

**Results**

In the 2D-images stemming from the µCT scanner with a spatial resolution of 6 µm, the alumina matrix could be well recognized, whereas the coating material was scarcely visible due to its low contrast (Fig. 1)

![Figure 1: µCT images of the Al\textsubscript{2}O\textsubscript{3} sample, axial and frontal view](image1)

A first overview of the sample was obtained by maximum intensity projection at reduced resolution, where a ring-like structure came to the fore (Fig. 2).

![Figure 2: First overview of the sample by maximum intensity projection. The small box indicates the section extracted for a more detailed analysis in Figure 4](image2)

For the whole sample, the “double” visualization as described in the preceding section could only be performed at a reduced resolution where we obliquely clipped the whole specimen for free view inside. A first impression of a “second” structure came to the fore (Fig. 3).
Figure 3: Obliquely clipped visualization of the whole sample, only the alumina matrix (left), alumina matrix and coating material (middle), and position of the clipping plane (small figure, right)

A comparable visualization of a cropped section of the sample, but with original resolution, revealed the macro-pores of the aluminium at an order of magnitude of 120 –150 µm. The double visualization allowed for detection of some micro-porous structure within the coating material (Fig. 4).

Figure 4: Cropped visualization of a section of the sample, only the alumina matrix (left), alumina matrix and coating material (right)

Finally, for the detailed visualization, we refer to the small section indicated by the little box given in Fig. 2. The resampling to a resolution of 2 µm enhanced the visibility of the inner structure of the coating material (Fig. 5). Even in the 2D-images, pores of the order of magnitudes of 20 – 40 µm, i.e. meso-pores, as well as pores of the order of magnitude of about 7 – 10 µm, i.e. micro-pores, could be revealed (Fig. 6). The latter ones are close to the resolution of the original µCT-data.
Figure 5: Section of a µCT image, original resolution of 6 µm (left) and resampled image with resolution of 2 µm (right)

Figure 6: Section of a resampled µCT image with measurements of pores at meso- and micro-scale

Based on the resampled images, the visualization referring to the double volume rendering enabled a 3D-analysis of the pores at meso- and micro-scale of the coating material (Fig. 7-9).
Figure 7: “Double” visualization based on the resampled data with the coating material in highly transparent rendering.

Figure 8: “Double” visualization with emphasis on the coating material without (left) and with (right) measurements of pores, mainly at meso-scale.

Figure 9: View of a detail, based on the double visualization with emphasis without (left) and with (right) measurements of pores, nearly at micro-scale.
Conclusion
By a “double” volume rendering approach applied to µCT images, it is possible to analyze composite porous biomaterials at macro-, meso-, and micro-level.

Acknowledgments
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References:
PICTURE CONTEST
Picture 1: from Annapaola Parrilli: Dental implant and biomaterial in cortical bone
Picture 2: from Annapaola Parrilli: Rat tibia and fibula
Picture 3: from Brian Hayes: Fibrosis in the mouse lung
Picture 4: from Francesca Salamanna: rat proximal femoral head
Picture 5: from Gerard van Dalen: bubbels
Picture 6: from Gerard van Dalen: carrot
Picture 7: from Gerard van Dalen: hair
Picture 8: from Gerard van Dalen: liquid sample holder
Picture 9: from Greetje Vande Velde: African fish lake Milawi
A study of a «sea slug» with the micro-CT Skyscan 1172 C

Javier Alba-Tercedor & Luis Sánchez
Tacira
University of Granada, Spain

Picture 10: from: Javier Alba Tercedor: Study of a sea slug
Picture 11: from James Hainfeld: MicroCT scan of live mouse kidney 2 min after iv injection of gold nanoparticle contrast agent (AuroVist-1.9nm, Nanoprobes, Inc.) showing functional clearance through the glomeruli and tubules.
Picture 12: from Jiri Valasek
Did we develop a new method for scanning living porcupines?

No, we scanned a polymer granule filled with glass fibres!


Picture 13: from Klaus Berdel
Picture 14: from Ken-ichi Itakura
Picture 15: from Kevin Mackenzie: child tooth with partially removed roots that have been resorbed by osteoclasts
Picture 16: from Maarten Depypere: bone implant with blood vessels
Picture 17: from Manoel D Sousa Neto: 1600 year old Mayans’ Teeth
Picture 18: from Marco Aurelio Versiani: a 3D reconstruction of the internal and external anatomy of a weird human tooth – a maxillary third molar – seen in different angles
Picture 19: from Molly Jackson: Maximum intensity projection of a small stone found growing out of a duct within a patient's kidney. This small stone was scanned using 50 kV, 198 mA, and a 0.5 mm Al filter. It was reconstructed with 4.2 µm voxels. MicroCT shows the three-dimensional relationship between different kinds of mineral. This analysis is used to find clues for the mechanism of formation of kidney stones.
Picture 20: from Raffaella Pecci: root canal with filler
Picture 21: from Francesca Zuppante: bone grafted with biomaterials
Picture 22: from Sinan Fidan
Picture 23: from Phil Salmon: carbon composite
Picture 24: from Phil Salmon: human femur diaphysis
Picture 25: from Phil Salmon: Hypisodus skull
Picture 26: from Phil Salmon: pig fossil tooth
Picture 27: from Phil Salmon: pig fossil tooth