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PALEORADIOLOGICAL TESTS IN HUNGARY AND ABROAD

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Although anthropology and archaeology have often taken separate paths, publications in recent years have demonstrated the importance of working together in these two areas to draw the right conclusions. At the same time, such projects also involve archaeozoologists, physicists, geneticists, and even radiologists. Imaging methods have been used in the study of the past since the nineteenth century. With them, we can examine not only human or animal remains but also archaeological finds. During our work, we have already studied ceramic vessels, metal objects, mummified human remains, human and animal bones. Radiological methods can be used to obtain additional information about the internal structure of bones, to reveal hitherto unseen defects in the case of a sword, or to examine in situ fragile grave goods lying in the middle of a lump of soil. In this paper, we present the theoretical background of radiological methods and their applicability in the fields of anthropology and archaeology, highlighting their advantages and limitations, to encourage as many members of the Hungarian professional community as possible to employ such methods.

Keywords: paleoradiology, paleopathology, X-ray, CT, human biology

INTRODUCTION

In the past few years, archaeology and anthropology have been getting increasingly intertwined in research. It is a common phenomenon in science that several disciplines, which have so far developed independently, join to further expand their knowledge. Archaeology reveals the past of mankind primarily through material evidence while integrating more and more scientific methods into its range of tools every year. Radiology, which is a branch of medicine, is one of these.

Paleoradiology is the study of finds discovered in archaeological contexts through the use of radiographic techniques, where images are taken with imaging technologies for data acquisition and proper interpretation. Paleoradiology research dates back to the late nineteenth century. Shortly after Wilhelm Conrad Röntgen (1845–1923) first described the phenomenon he called ‘X-ray’ in 1895 (Dunn 2001), Koenig (1896) applied the new discovery to the study of human and animal mummies the following year. The term ‘paleoradiology’, on the other hand, took nearly a hundred years to emerge (Notman et al. 1987).

This imaging method can be used to examine not only the remains of humans and other living creatures but also archaeological artefacts (Beckett 2014). In this way, they allow us to see changes that would not be macroscopically visible. Additionally, it enables us to perform quantitative analyses of the bone structure. We can even observe the various metal inlays of highly corroded objects and their manufacturing, as well as reveal the clay structure, preparation technique and contents of pottery vessels, and even study samples that are hard to access or too fragile (e.g. a mummy lying in a sarcophagus) to be examined with other methods.

The advantage compared to clinical tests is that in this case we do not need to be worried about the radiation exposure (ALARA[3] principle) of the subjects (bones and other archaeological finds), so we can take far better images of a certain artefact or remain in order to obtain as much information as possible about its condition, raw material, and preparation technique. However, in the case of bones, we must be careful if we also want to take a DNA sample from a given individual, even though one study suggests that the radiation

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[3] ALARA stand for ‘As Low As Reasonably Achievable’. This is a principle of radiation safety and diagnostic imaging, according to which the desired diagnostic result must be obtained with the lowest dose of radiation reasonably achievable.

dose used by conventional X-ray, CT, and microCT machines does not reach the critical level that could damage the valuable hereditary material, which can be subjected to paleogenetic tests (Immel et al. 2016). Alternatively, if the nature of the sample makes it possible, magnetic resonance imaging may also be carried out (Rühli et al. 2007a; Eppenberger et al. 2018).

In the present study, we will be presenting the working principles of traditional radiology, computed tomography (CT), and microcomputed tomography (microCT), their applicability in archaeology and anthropology, as well as their benefits, drawbacks, and limitations by reviewing the scholarly literature and presenting examples from our own research.

METHODS

Conventional radiology

The prerequisite for traditional X-ray imaging is that the X-rays emitted by an X-ray tube reach the film or digital detector after passing through the test object. The radiation attenuation coefficient describes the extent to which the radiant flux of a beam is reduced as it passes through some specific material and how much radiation reaches the detector. The amount of X-rays passing depends on the atomic number, density, and thickness of the test material, as well as the wavelength of the radiation (Fráter 2015). The X-ray would normally blacken the image seen, but depending on the properties of the object in its path (e.g. due to its mineral content), it can get absorbed, resulting in a white pattern on the image (Fráter 2015; Immel, DiMeglio & Burr 2014).

Computed tomography

In the case of plain X-ray imaging, a two-dimensional, summative image is taken of the sample, so its three-dimensional structure is lost. This can make the interpretation of the image difficult, as the different points of a skull, for example, overlap each other, which can be confusing. This problem may be partially eliminated by taking X-ray images from different angles, but real three-dimensional information can be obtained with computed tomography. The CT scanner takes a large number of separate X-ray images of the subject while moving the X-ray source and the detector opposite it in a straight line along the axis of the body, as if slicing a loaf of bread (translational motion). Stopping at each slice, the X-ray source and detector also rotate around the body (rotational motion). The computer can reconstruct a 3D image using the data gathered this way (Fráter 2015).

Micro-computed tomography

MicroCT is based on a similar principle to CT, but on a small scale with a massively increased resolution that varies in the micrometre range (3–500 µm) depending on the device (Vásárhelyi et al. 2020). This enables researchers to slice the sample up at a resolution close to that of light microscopes but still non-destructively in order to reveal its three-dimensional internal microstructure. Although most of these devices can only hold samples of a few centimetres, in return, we can also perform detailed quantitative measurements. When we subject bone samples to clinical research, we often examine the relative proportions of spongy and compact bone, the thickness and volume of these two types, the number of microscopic trabeculae in the spongy bone and the number of connections between them, as well as the presence of various diseases (Campbell & Sophocleous 2014). It cannot be ruled out that such studies will later become common in the case of bio-archaeological samples as well.

RADIOLOGY USED IN ARCHAEOLOGY AND ANTHROPOLOGY

Pottery and metal finds under the X-ray tube

Not only bones but also ceramics and metal objects may hold secrets beneath the surface. In 2021, a portable X-ray scanner developed for veterinary use was purchased by the Szent István Király Museum, which opened up new perspectives for us. We have already been able to test the device on several types of finds in our research. Special mention should be made of the radiological analysis of the ceramic grave-goods from the newly discovered Avar cemetery at Csákberény-Arató-szérű. At the end of the excavation and before the restoration, we took an X-ray of each intact ceramic vessel still filled with soil to maximise the amount of data we can collect about them. This valuable information is normally lost fully or partially when the vessels are uncovered, cleaned, and restored. We can find examples of similar tests in literature since the 1930s (Berg 2008; Karl et al. 2014). The outline of the vessels became perfectly visible beyond all manual measurements and drawings, so the shape of the pottery find was also recorded to scale together with a profile drawing (*Fig. 1*). Another advantage of X-ray scanning is that in the case of hand-made pottery, we can reconstruct the process of manufacturing. We can also observe the defects that are invisible to the naked eye, as well as the attempts made to repair them. The most interesting observations were, however, related to the contents of ceramics. Since these finds came from an Avar cemetery, we did not expect to find anything else than seeds and food remains in the pots. Without X-ray, however, we would not have realised that the contents of the vessels were layered. We can assume that the lower layer was the original content, whereas in the upper part we can see the soil that fell in the vessels subsequently. This finding may be important for such vessels because it allows us to tell more accurately where paleobotanical or other samples are worth being taken. Our idea has yet to be substantiated by sampling, but we strongly recommend X-rays of similar finds at such an early stage of processing.

Fig. 1. X-ray of a pottery vessel filled with soil belonging to burial SNR 04 at Csákberény-Arató-szérű.

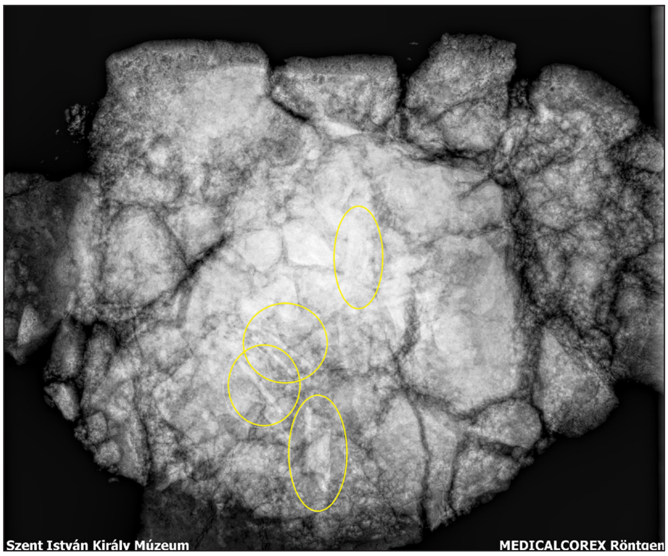

Fig. 2. X-ray of a damaged urn found in Kajászó-Keskeny-dűlő.

Unfortunately, if an urn is too large, it will be difficult to scan it with an X-ray device. We also encountered this problem in the case of the Bronze Age urns taken to our repository from Kajászó. For the inspection of large urns that contain several vessels and grave-goods, it is better to use a CT (Higgins et al. 2020) or an industrial X-ray machine. However, in the minor urns we observed small bone remains, and it was also possible to assess in advance that they did not contain any metal finds (*Fig. 2*).

In the case of metal objects, we can learn more about the method of production and the decorations that are no longer visible with the bare eye. Again, to mention an example from the collection of our museum, X-rays were taken about the tenth- and eleventh-century swords discovered in the territory of Székesfehérvár, the assessment and publication of which are still in progress (*Fig. 3*) (Zágorhidi-Czigány et al. 2021).

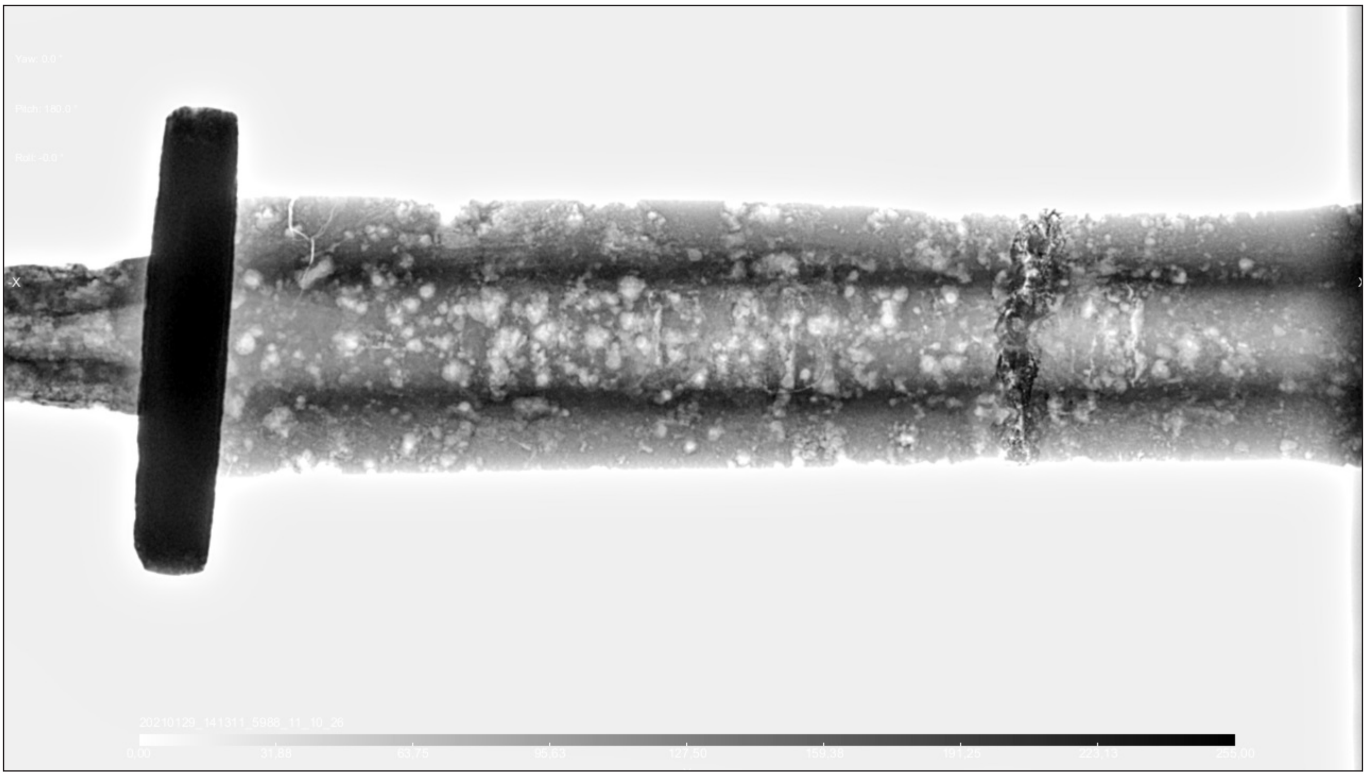

Fig. 3. X-ray scan of one of the swords from Székesfehérvár-Rádiótelep, transformed into a different colour scale with the Dragonfly image analysis software.

Testing bones and mummies

In the case of human and animal remains – unless they are mummified – normally the skeletal system can be examined. It is mainly its mineral content (especially in the form of calcium and phosphate *hydroxylapatite*) that is able to absorb a significant portion of the X-rays. The bone matrix is synthesised on a daily basis by bone-forming cells (*osteoblasts*) and is degraded by bone-resorbing cells (*osteoclasts*), which processes are balanced in healthy bone tissue. If this balance is disrupted due to some pathological process or the aging of the body, its consequence can also be seen in radiological images (Fonyó 2011; Allen & Burr 2014).

A given disease can lead to a decrease in the mineral contentof bones either systemically (e.g. in *osteoporosis*) or in a well-defined area (e.g. during inflammation), or can be manifested as an increase of its mineral content (e.g. in the case of a benign bone tumour called *osteoma*). In addition to the pathologically structured mineral content (e.g. in the case of *osteodysplasia*), the shift in the proportion of organic and inorganic components of the bone is also considered to be a fundamental change. For example, during *osteogenesis imperfecta*, the proportion of the organic constituent is lower and/or of poorer quality. The last fundamental change to be mentioned is the necrosis of the organic components of the bone, which can be observed during bone infarction (*osteonecrosis*), for example. If, in addition to the fundamental changes observed, we also take into consideration the exact locations of these lesions, changes in the shape of bones, the sex and age of the individual, we can make a final diagnosis or get very close to it (Fráter 2015).

In Hungary, the term paleoradiology is mostly associated with anthropological investigations and is often used as a part of paleopathological analyses, but it has also been applied in research at the population level. We performed such population-level analyses on the anthropological material discovered in the Avar and tenth-century cemeteries at Bodajk, as well as in Szentmártoni út and site No. 22 in Albertirsa. From the international research, the publication Papagrigorakis et al. (2012) is an excellent example of this approach. A total of 240 contemporary and 141 historical skulls were scanned from three angles. According to the results, *osteoporosis* was demonstrated in the case of seven skulls of historical age. Another main goal was to study the shape of the "Turkish saddle" (*sella turcica*) containing the pituitary gland because it can get distorted as a result of many underlying diseases. Altogether 28 skulls showed various malformations of this region, which suggests either anatomical variations or certain diseases (e.g., Down syndrome, Prader-Willi syndrome, meningeal tumour, aneurysm, Rathke cleft cyst, Wermer syndrome, pituitary tumours, hypothyroidism, or an earlier basilar skull fracture).

A sore point with paleopathology is that researchers cannot perform systematic radiological "screenings" on cemeteries with tens, hundreds, or sometimes thousands of graves. Therefore, there may be several diseases inside the bones that remains hidden. During our research on the site Kehida-Fövenyes, we used imaging techniques in multiple cases (Kiss et al. 2019). In the case of a late Avar male around the age of 30–40 years at death, the benign tumour of the frontal bone (*osteoid osteoma*) would have been left unobserved without a radiological examination. Likewise, a Roman skull discovered as a stray find at the site Bécsi street 102, District 3, Budapest, under the supervision of Fanni Fodor, also caused an intriguing surprise for us. We could see the thinned parietal bone and the imprints of the abnormally thick blood vessels on the inner surface of the skull. The skull was slightly deformed and the sutures of the skull were fused together almost without a trace. It is plausible that this can be attributed to the bone formation disorder of the sutures. A 3D model and an X-ray image were also taken of the skull. In the latter, we have discovered a pattern in the left parietal bone, suggestive of the lesion of vascular tissue origin, which is the developmental anomaly of the emissary veins connecting the extracranial venous system with the intracranial venous sinuses (*Fig. 4*).

Fig. 4. The internal structure (diploë) of the left parietal bone shows a developmental variation of the vena emissaria connecting the external and internal veins of the skull.

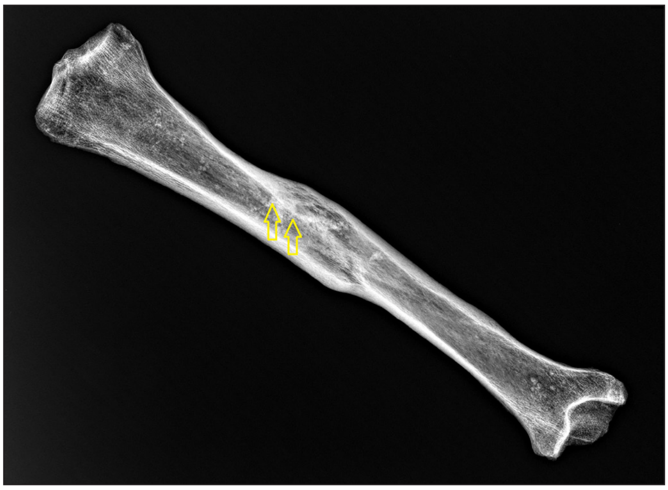

Fig. 5. Radiological image of a broken tibia (diaphysis) healed with axial misalignment and lateral shift. The line of the original cortex (compact bone) can also be observed.

Imaging procedures also help to describe more precisely the pathologies (lesions caused by a disease) already identified. For example, concerning the bony fusion of the tibia and fibula (*tibiofibular synostosis*) of a 20–25-year-old woman discovered at the Kehida-Fövenyes site, we found that the anomaly was caused by the continuous micro-injuries of the joint between the two bones after their longitudinal growth finished. We also got a more accurate picture of the locations of skeletal alterations in the case of a 45-50 year old man excavated at Kehida-Fövenyes site. More lesions were revealed by the CT scans which suggested –considering the age and the sex as well – the possibility of prostate cancer. X-rays may also help us to observe healed fractures and identify the origins of thickened bones that can be seen with unaided eyes, that is, whether the morphology seen was caused by myelitis or a healed fracture (*Fig. 5*).

It can be particularly useful to have virtual X-ray eyes when studying an Egyptian mummy lying in a sarcophagus or the related human organs placed in canopic jars. In the case of mummies, radiological images may reveal not only the internal organs but also the bones covered by soft tissues. Hungarian researchers could experience this benefit on multiple occasions during the research of the Vác mummies, where CT images helped to identify, among other things, one of the clear signs of tuberculosis infection, namely, the calcified tubercles (Ghon lesion) found in the lung tissues of several deceased individuals (Pap

ET AL. 1999). Recently, the use of both CT and X-ray machines proved to be indispensable in the examination of human remains discovered in the famous Szapáry-Eötvös Chapel in Ercsi, Fejér County,[4] as without these techniques we would not have been able to determine the age and sex one of the naturally mummified remains, nor study its bones and joints (*Fig. 6*). It could also be demonstrated that there was no degenerative (pathological) abnormality in the joints of the adult male.

Fig. 6. Image of a naturally mummified body part discovered in Ercsi.

CT scans not only allow us to discover diseases but they can also be used to reconstruct people's lifestyles. From the cross-sectional geometry of long bones, we can assess to what extent a given individual/community led a physically active lifestyle (JURMAIN ET AL. 2011).

Occasionally, histological sections need to be taken from the archaeological remains for making a differential diagnosis.[5] In this way, we can see on a cellular level the pathological processes that took place in the bone tissue. At the same time, it damages the sample, and does not allow us to observe the 3D structure of the lesion either. MicroCT, though not in such good resolution, is able to substitute for paleohistological analyses (i.e. the examination of tissue remains of historical age) partially. It provides us with information in an automated way and faster than histological analysis. However, for assessing the pattern of collagen fibres and for differentiating between the mature and immature bone tissues, polarized light microscopy still seems to be a more suitable method (RÜHLI ET AL. 2007b).

SUMMARY

Images yielded by paleoradiological analyses not only support research but can also be used in education and dissemination. We can create three-dimensional models that may as well be printed out to be used in classrooms or as replicas in exhibition spaces and they can also be sent for examination to a colleague across the Atlantic who cannot visit us to do research here or have a personal discussion due to the epidemic or other reasons. Looking through scholarly literature, we can find an extremely wide range of paleoradiological methods and their applications. In the current study, we have presented a small section of this diversity through examples taken from publications and/or from our own research to illustrate what key role these methods could play in domestic research as well. In Hungary, conventional radiography and CT scans are used predominantly in paleoradiological work, which techniques add brand new details to our knowledge of our past in the case of pottery, metal, and bone finds alike.

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[4] For the CT scans, we are indebted to the Dr. Baka József Diagnostic, Oncoradiological, Research and Teaching Centre of the Kaposi Mór Teaching Hospital.

[5] Differential diagnosis is a diagnostic method for distinguishing a particular disease from others in diagnosis based on the patient's symptoms and the necessary additional tests.

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