NON-DESTRUCTIVE TESTING OF WORK-RELATED HYPERTROPHIC ALTERATIONS OF THE HORSE METATARSUS, DEMONSTRATED THROUGH THE EXAMPLE OF SCYTHIAN AGE HORSE REMAINS

A LÓ LÁBKÖZÉPCSONT MUNKAHIPERTRÓFIÁS ELVÁLTOZÁSAINAK RONCSOLÁS MENTES VIZSGÁLATA, SZKÍTA KORI LÓMARADVÁNYOK PÉLDÁJÁN BEMUTATVA•

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Abstract

*Recently we have managed to elaborate a method to evaluate the permanent marks caused by work and lifestyle on horses' metatarsus, which is suitable to establish – even in the absence of associated artefacts - the way horses of archaeological age were used. The structure of the metatarsus is most typically characterising the specimen in the zone of f.n. (*foramen nutricium*), therefore this was the location where we prepared across sectional ground sample, serving as the basis of the analyses. Recently in several projects we have faced the problem that - for reasons of the protection of cultural heritage artefacts - it is just the most important finds in the case of which bones should not be examined in a destructive manner, i.e. by preparing cross-sectional ground samples as we do when applying the basic method. Furthermore, the high demand for such testing also required us to elaborate a faster and non-destructive method of the analysis the metatarsus-cortex. On the recent level of technological development, theoretically there are two widely available options for that: magnetic resonance imaging and computed tomography, however, our experience shows that in archaeological practice only the latter is usable. We tested the new method through the examination of the horses of the Csanytelek-Újhalastó and Szentes-Vekerzug Scythian cemeteries; the experience gained, and the lessons learnt from these tests, important from the viewpoint of methodology, will be described herein. The result of the tests conducted to analyse hypertrophy caused by work in the horse remains of the above-mentioned cemeteries will be published in the separate study.*

Kivonat

*A közelmúltban sikerült kidolgozni egy módszert a lovak lábközépcsontján a munkavégzés és az életmód okozta maradandó nyomok értékelésére, amely alkalmas a régészeti korú lovak használati módjának meghatározására a mellékletektől függetlenül is. A lábközépcsont szerkezete a f.n. (*foramen nutricium*) magasságában a legjellemzőbb az egyedre, ezért itt készítettük az elemzések alapjául szolgáló csiszolt harántmetszetet. Az elmúlt időszakban azonban több projekt esetében is szembesültünk azzal, hogy műtárgyvédelmi okok miatt éppen a legfontosabb leletek esetében nem megengedhető a csontok roncsolással járó vizsgálata, az alapmódszer szerinti csiszolt harántmetszet elkészítése. Továbbá a vizsgálat iránti nagy igény is szükségessé tette, hogy kidolgozzuk a lábközépcsont-kéregállomány vizsgálatának gyorsabb és roncsolás mentes módszerét. A technológiai fejlettség mai szintjén elméletben erre két széles körben elérhető lehetőség van, a mágneses rezonancia képalkotás és a komputertomográfia. A régészeti gyakorlatban tapasztalataink szerint csak az utóbbi használható. Az új módszert Csanytelek-Újhalastó és Szentes-Vekerzug szkíta kori temetők lovainak vizsgálatával teszteltük, melynek ezúttal módszertani szempontból fontos tapasztalatait, tanulságait adjuk közre. Az előbb megnevezett temetők ló maradványainak munkahipertrófiás vizsgálati eredményeit önálló tanulmányban adjuk közre.*

• How to cite this paper: BOZI, R. & SZABÓ, G., (2021): Non-destructive testing of work-related hypertrophic alterations of the horse metatarsus, demonstrated through the example of Scythian Age horse remains / A ló lábközépcsont munkahipertrófiás elváltozásainak roncsolás mentes vizsgálata, szkíta kori lómaradványok példáján bemutatva, *Archeometriai Műhely* **XVIII/3** 273–288.
doi: 10.55023//issn.1786-271X.2021-020

KEYWORDS: NON-DESTRUCTIVE TEST, HORSE, LIFESTYLE, WORK, METATARSUS, OSTEOMETRY, SCYTHIAN AGE

KULCSSZAVAK: RONCSOLÁS MENTES VIZSGÁLAT, LÓ, ÉLETMÓD, MUNKAVÉGZÉS, LÁBKÖZÉPCSONT, OSTEOMETRIA, SZKÍTA KOR

Introduction

A direct precedent to our present work was the method we have recently elaborated to objectively reveal the permanent marks the work performed by horses and their lifestyle left on their metatarsus. This method is suitable to establish – even independently from grave goods - the way horses of archaeological age were used (Bozi & Szabó 2020). The structure of the metatarsus reflects most typically the permanent marks left by the specimen's life history in the zone of f.n. (*foramen nutricium*); therefore, this was the location where we produced cross-sectional ground samples, serving as the basis of the analyses. The project called *"Riding and cart horses in the archaeological cultures of the Eurasian steppes in the XX-III cent. BC (on materials of horse equipment and archaeozoology)"* covers an extremely wide area expanding from China to the Danube. It aims to examine the way in which the remains of the harnesses and the carriages observable in the graves from the 2nd millennium B.C. found alongside horse bones reflect the process of social, economic, and cultural changes in the Eurasian steppes and Southwest Asia. These changes were triggered by starting to use horses for work. Special importance was attached to horses in the1st millennium B.C. among the pastoral societies of the Eurasian steppe, where they became the basis of livelihood and they were used in farming, herding cattle, hunting and also in warfare. Horseback riding became widespread from the 9th–7th century B.C., mounted warriors appeared, as well as military cavalry units led by the elites of mobile pastoral societies. The decoration of the horse harnesses at the same time reflected the status of the warrior and the horse was seen as a sacral animal, thus it was part of ritual acts and often buried near its master in the grave. The image of riding horses and cavalry, known since the Scythian age, affected so strongly the thinking of researchers that up to these days almost all the horses and harnesses from the 9th–3rd century B.C. between the Danube River and the Transbaikal region were interpreted as being and belonging to riding horses, unless a wheel was also found near them that clearly referred to carts. However, in recent years based on a more detailed analysis of archaeological finds the idea is increasingly emerging that a significant part of the harnesses, in particular ones from the 9th–7th century B.C., may have belonged to the equipment of draft horses, which may considerably change the idea developed so far concerning the economy, society, way of daily life and belief system of the specific period.

Up to now the possibilities of testing horse usage have been significantly restricted by the lack of a method that could be used to clearly decide, either based on the archaeological objects or the bones, whether they belonged to mounts or draft horses (Bendrey 2007; Taylor & Tuvshinjargal 2018). Therefore, in the international project one of the main tasks of the Hungarian researchers is to determine the way in which the horses of the period were used by applying their osteometrical methods. However, in the case of the first Scythian artefacts we had to face the problem that - for reasons of cultural heritage protection - it is just the most important finds in the case of which bones should not be examined using destructive methods, i.e. by preparing cross-sectional ground samples. The project's goals and the high demand for testing the work-related hypertrophies (Bartosiewicz et al. 1993) also required us to elaborate a faster and non-destructive analysis of the metatarsus-cortex. On the recent level of technological development, theoretically there are two widely available options for that: magnetic resonance imaging (MRI) and computed tomography (CT).

In the enhancement of the basic method, as the first step, we performed a CT scan of the previously made cross-section ground samples of the metatarsi of horses with known life history, 1-2 mm proximally of the *foramen nutricium*. The reason for the proximal deviation from the f.n. is that a previously excised bone was the subject of the test.

The comparative analysis of the data of the images obtained using different procedures (section, CT image) have shown that the section images produced with a non-destructive method can be analysed as successfully as the ground samples. In the second phase of research, we tested the new procedure by examining horses of archaeological age. The data of the horses selected for analysis also pointed out that beside the benefits of the effective use of non-destructive imaging devices in archaeological practice certain constraints must also be taken into consideration. We tested the suitability of images produced in a non-destructive way for work hypertrophy examinations through the analysis of the Scythian horses of Csanytelek-Újhalastó and Szentes-Vekerzug. The experience gained and the lessons learnt from these tests are important from a methodological point of view. The detailed and comprehensive results of work-related hypertrophic tests will be published separately due to their excessive length.

Equipment and methods

Magnetic resonance imaging

The experiments we conducted prove that the MRI used in medical diagnostics is not suitable for producing the desired image. Depending on the selected characteristics of the radio wave and the magnetic field – based on physics – the connection is established only with specific nuclei. For example, the generally used version of the MRI utilizes the nuclei of hydrogen atoms, the protons. The process can be further narrowed down to ensure that the response would come from the protons of the water molecules making up approx. 70% of the body. Naturally, the image of several other stable isotopes may also be used (Vandulek 2014 T. 28.4). Hydrogen exists in living organisms in a high concentration, mainly because of the water content (Emri 2011, 18). The archaeological bone finds, however, typically contain only a low concentration of water, and our experience shows that even after soaking them, their water concentration is not sufficient for producing an MRI image (**Fig. 1.**).

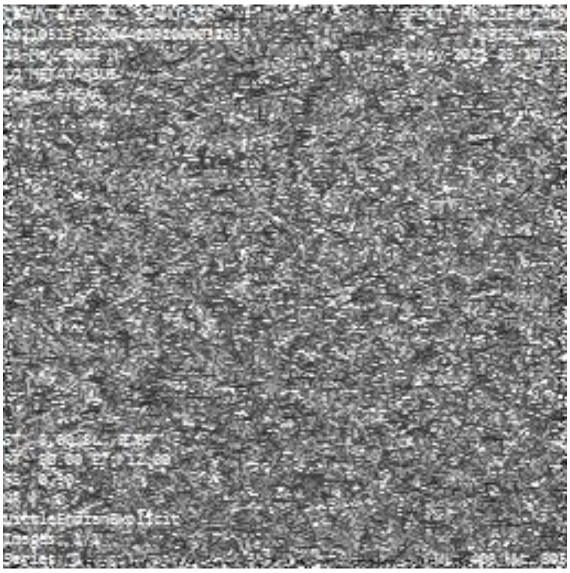

Fig. 1.: Csanytelek–Újhalastó MRI scan of Scythian horse metatarsus III. bone after soaking in water. The measurement has not even started due to the absence of stimulable atoms

1. ábra: Csanytelek–Újhalastó szkíta kori ló III. lábközépcsontjának vizes áztatás utáni MRI felvétele. Gerjeszthető atomok hiányában a mérés el sem indult

Computed tomography

The device we used is a Ge Lightspeed 4-slice CT manufactured in 2008 (**Fig. 2a-b**). It is a high performance (~50 kW) X-ray tube, with a so-called detector arc positioned opposite the tube, which rotates around the examined body. For tomographic image reconstruction an optimal number of projections are necessary to be made, therefore during rotation the device gathers planar attenuation images of the area to be examined, per each ~0.1 degree. The algorithm of the CT reconstruction determines the μ factors characterising radiation attenuation in the individual points of the body. The turn-around time (Trot) today is generally lower than 1 s, and in the case of faster CT devices it may even reach the value of 0.3 s. Fast rotation is necessary so that the person or the part of the body would move as little as possible or would not move at all during the scan. Several parameters influence the image quality of CT scans, among others the ones that can be set in the equipment. Among these the most important is the voltage of the X-ray tube (80-140 kV) and its amperage (50-500 mA), the Trot (0.3-1 s), the pitch (0.2-2). Moreover, a number of additional factors also affect it, such as the specific algorithm of image reconstruction, and its settings (in a reconstructed image the number of pixels, the application of special filters, etc., the size of the object examined (Balkay 2011, 104). In our case the small size of the object and its immobility made it easier to record an image. Out of the available equipment types in our trials, computed tomography proved to be the most suitable and most cost-efficient tool for the non-destructive testing of the internal structure of bones of archaeological age (**Fig. 2a-b**).

Positioning the test material, producing the sectional image

The phenomena detected on the metatarsus cortex, the method of extracting information, the interpretation of the extracted information, and the conclusions drawn are the same as in the case of the basic method (Bozi & Szabó 2020). However, the image to be examined is produced in a completely different way. The bone is not damaged. We use the computed tomograph scanner to produce an image at the place where a cross-section would be cut out when using the original method. The preparation and setting of metatarsus III is performed as follows. We mark the plane of the rear panel of the metatarsus. We use a plastic T-plate for determining the plane of the rear panel, instead of a metal one as we do in the case of the original method. Metals absorb and scatter X-rays effectively, and therefore in many cases make the resulting image impossible to evaluate. The T-plate was prepared in 2 sizes, due to the anatomical variability of bones (**Fig. 3.**).

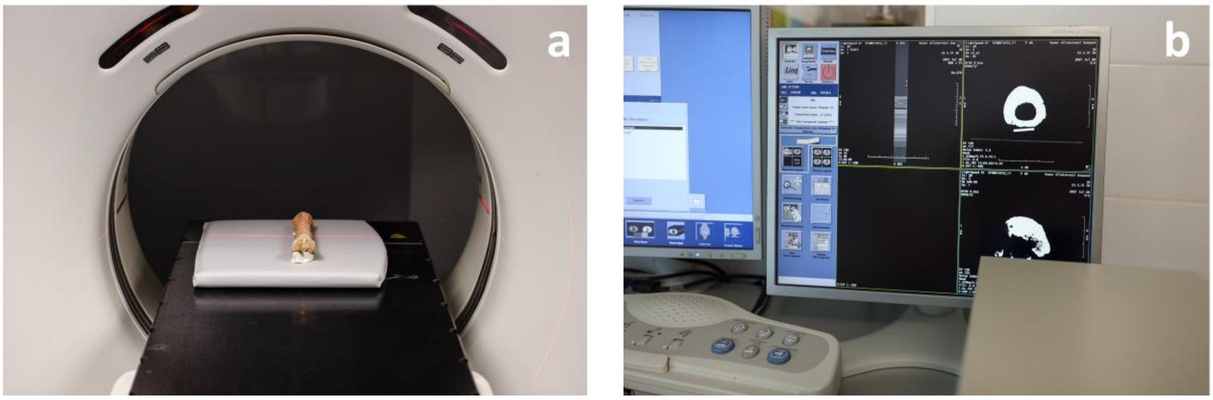

Fig. 2a-b: a) Ge Lightspeed 4-slice CT with a horse metatarsus set in a measurement test position b) DICOM file containing all image settings is displayed on the monitor

2a-b ábra: a) GeLightspeed 4-slice CT mérési pozícióba állított ló lábközépcsonttal b) A monitoron az összes képbeállítást tartalmazó DICOM fájl látható

Fig. 3.: T-plates for determining the plane of the rear panel

3. ábra: T-lapocskák a hátfal sík meghatározásához

I. The length of the stem is 60 mm, its width is 15 mm, the length of the arm is 40 mm, its width is 10 mm, the thickness of the material is 2 mm.

II. The length of the stem is 40 mm, its width is 15 mm, the length of the arm is 40 mm, its width is 10 mm, the thickness of the material is 2 mm.

The stem of the proper-size T-plate is adjusted to the proximal fingertip-like imprint on the plantar surface and fixed with self-adhesive flexible plasticine (Pritt) preventing tilting. The outer edge of the arm lies on the transverse diameter of the *foramen nutricium*, approximately perpendicular to the longitudinal axis of the metatarsus (**Fig. 4a-b**).

The prepared metatarsus is entered into the CT scanner in the following way. The positioning of the longitudinal laser beam falls on the longitudinal axis of the metatarsus and lies distally along the edge of the *crista articularis*, and proximally on the *tuberositas metatarsi*, on the approximate medial tierce point of the highest section of the dorsal edge. It is important that in the course of the testing the metatarsus should be in a dorsally horizontal position in order to reach a perpendicular sectional image, therefore the proximal and distal ends should be propped up with plasticine to prevent tilting, then adjusted by using a spirit level (**Fig. 5a-b**). Correct positioning is necessary to ensure that the generated radiation beams form the most accurate cross-section image possible, and this causes the measurement to be within the error limit. Precise positioning is the basis for a uniform measurement protocol. This allows the measurement to be reconstructed at any time. The results of the metatarsus analysed this way are comparable and realistic conclusions can be drawn from them (**Appendix 1.**).

By taking advantage of the possibilities offered by CT method, we produced a series of cross-sectional images at the target area of the properly positioned metatarsus, and for the measurement we use the image produced at the *foramen nutricium*. The images were produced with 120 kV and 80-118 mA setting, without a filter. The DICOM file manager program of the CT equipment in "bone window" mode creates a black and white image from the grayscale image, which is well apparent on **Fig. 2b**. By using the Micro DICOM program, this image is converted into JPG format to ensure easier exportability (**Fig. 6a-b**). This image corresponds to the ground, painted section produced using the basic method (Bozi & Szabó 2020, Fig. 9).

Fig. 4a-b: The manner of positioning T-plates
4a-b ábra: A T-lapocskák felhelyezési módja

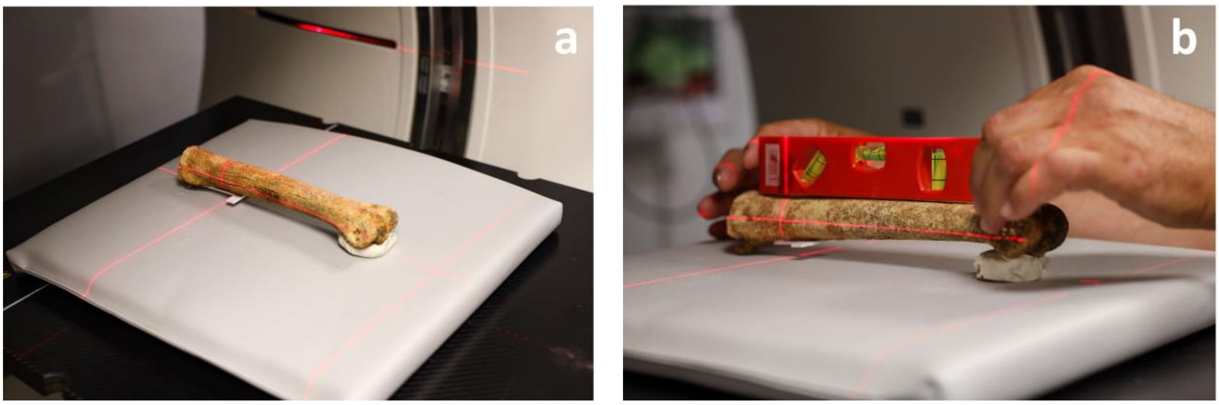

Fig. 5a-b: Positioning the metatarsus for CT scans
5a-b ábra: A metatarsus pozicionálása a CT vizsgálathoz

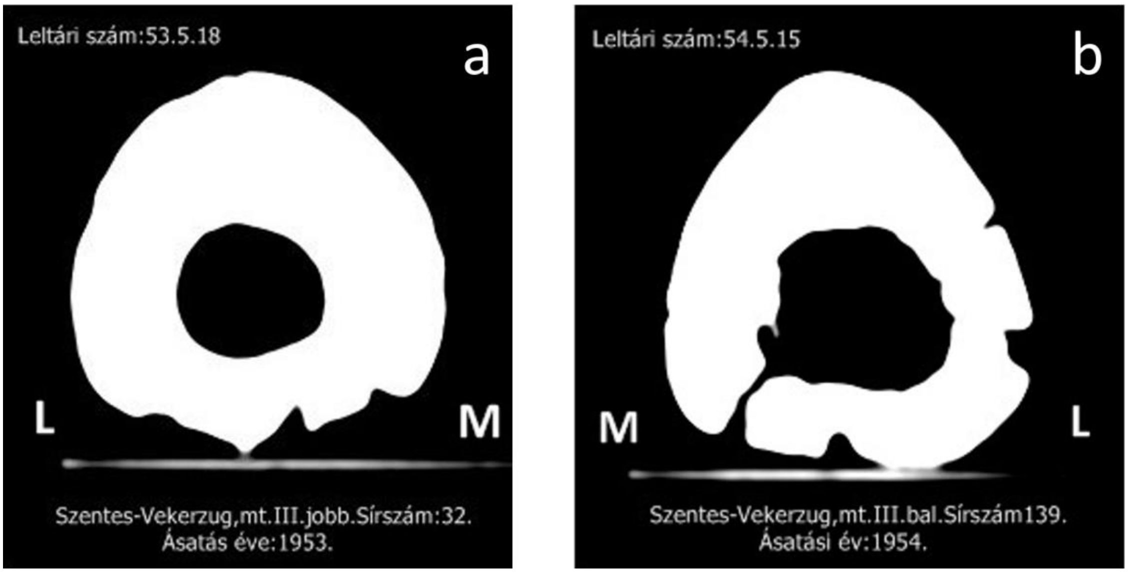

Fig. 6a-b: Well positioned assessable contrasting CT images (M: Medialis, L: Lateralis)
6a-b ábra: Jól pozícionált, értékelhető kontrasztos CT felvételek (M: Medialis, L: Lateralis)

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After drafting the relevant lines on the CT sectional image, by placing on the image the 5° scaled template printed on transparent foil, the measuring points could be marked accurately and quickly and the data necessary for the previously described formula could be recorded. The measurement is performed manually Bozi & Szabó 2020, 77-79) (**Fig. 7a-b**).

Destructive and non-destructive comparative test of recent horse metatarsus III bones

We compared the mechanically sectioned slice and CT image of the same bone to check whether the CT image is suitable for revealing the required information on the metatarsus.

The summary diagrams of the load extent and the location of the maximum cortical stock width (C_{maxloc}) are presented in our baseline study (Bozi & Szabó 2020, Appendix Tab. 1).For the analysis we compared the sectioned and CT image of the metatarsus of a 12-year-old Hungarian half-bred gelding used in a farm in a horse-drawn cart (**Fig. 8a-e**) and a 17-year-old Hungarian half-bred gelding used as a mount used in long-distance riding (**Fig. 9 a-e**).

It is apparent from the data included in the table summarising the location of the maximum width of the cortical bone and the intensity of load (**Table 1.**) that the comparison of the values yielded by the section and the CT image shows some difference, but the apparent deviation of a few percentages does not significantly affect the conclusions that can be drawn. All in all, the data prove that a well-produced CT image is suitable for revealing actual information, similarly to sections. The reason for the difference is partly the different testing method, and the slightly different positioning of the image recorded of the section after the cutting.

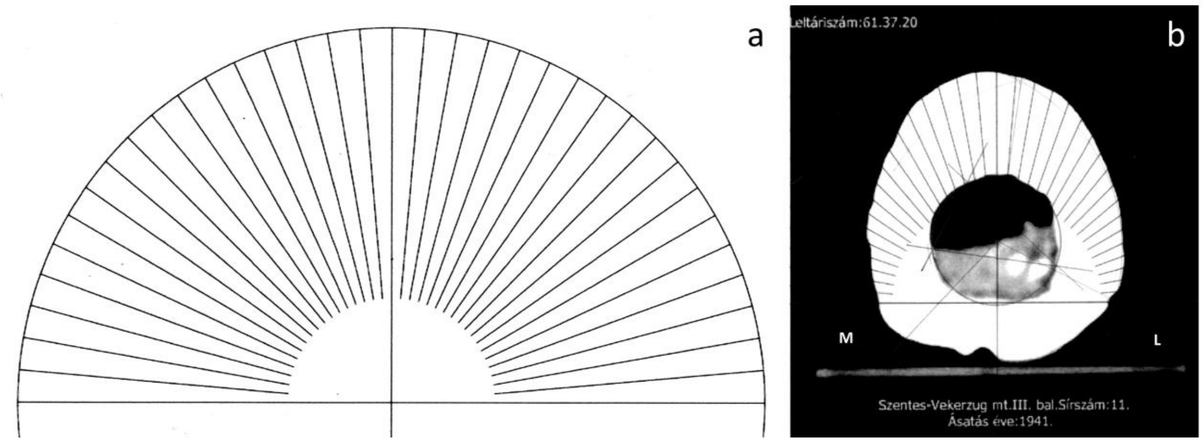

Fig. 7a-b: a) 5° scaled template, b) Template positioned on CT image with relevant lines (M: Medialis, L: Lateralis)

7a-b ábra: a) 5°-os beosztású sablon, b) CT felvételre helyezett sablon az irányadó egyenesekkel (M: Medialis, L: Lateralis)

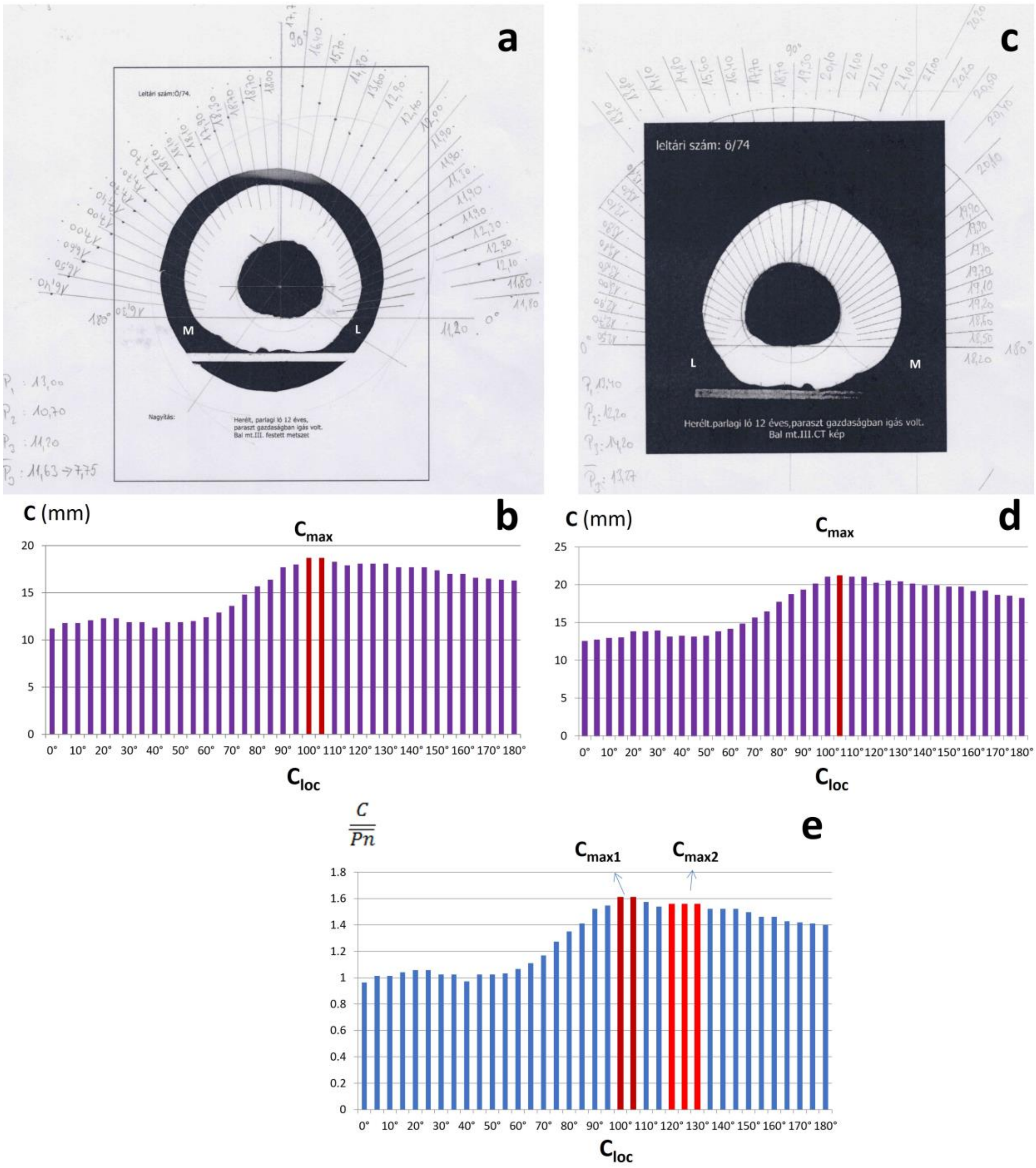

Fig. 8a-e: a) Horse used in horse-drawn cart (ö/74) metatarsus III ground section (M: Medialis, L: Lateralis), b) Distribution of cortex width measured on the section, c) CT image, d) distribution of cortex width measured on the CT image, e) Load intensity (C: cortex width; $C/\overline{P}_n$: mathematical average of the cortex width of the plantar area; C_{loc}: location of the cortex width)

8a-e ábra: a) Fogat ló (ö/74) metatarsus III. csiszolt metszete (M: Medialis, L: Lateralis), b) A metszeten mért kéregállomány szélesség megoszlása, c) CT kép (M: Medialis, L: Lateralis), d) A CT képen mért kéregállomány szélesség megoszlása, e) A terhelés intenzitása (C: kéregállomány szélesség; $C/\overline{P}_n$: hátfal kéregállomány szélesség matematikai átlaga; C_{loc}: kéregállomány szélesség)

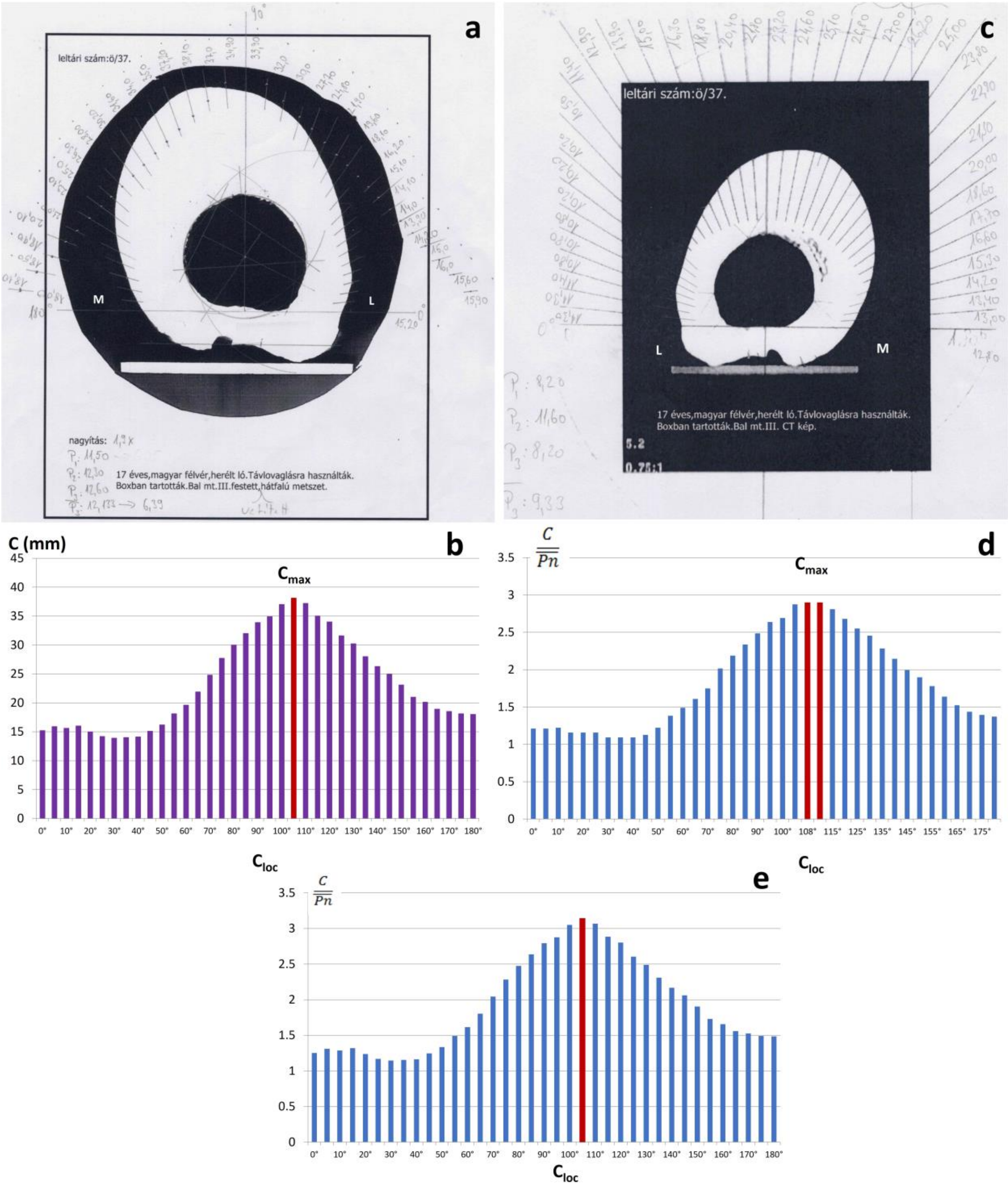

Fig. 9a-e: a) Riding horse (ö/37) metatarsus III ground section (M: Medialis, L: Lateralis), b) Distribution of cortex width measured on the section, c) CT image (M: Medialis, L: Lateralis), d) Load intensity measured on the CT image; e) load intensity measured on the section

9a-e ábra: a) Hátas ló (ö/37) metatarsus III. csiszolt metszete (M: Medialis, L: Lateralis), b) a CT képen mért kéregállomány szélesség megoszlása, c) CT kép (M: Medialis, L: Lateralis), d) A CT képen mért terhelés intenzitás; e) a csiszolt metszeten mért terhelés intenzitás

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Table 1: Measured and calculated values of the bone cortex width of metatarsi (by Bozi & Szabó 2020, 77-78) used in the methodological study

1. táblázat: A módszertani tanulmányba bevont metatarsusok csont-kéregállományának mért és számított értékei (Bozi & Szabó 2020, 77-78 alapján)

Inventory number	$\bar{P}_n$ ±0,01	***Cmax*** mm ±0,01	***Cmaxloc*** angle degree ±1° X	$\boldsymbol{Cmax_{97-100\%}loc}$ angular range ±1° Y	***Load intensity*** $\frac{Cmax}{\bar{P}_n}$	***Durability of load*** $\left(\frac{Cmax}{\bar{P}_n} \times \sin \text{⍰}\right) \times 10$	***Life history*** $\left(\frac{Cmax}{\bar{P}_n} \times \frac{1}{\sin Y}\right) \times \cos X^2$
ö/74, CT	13.27	20.50	125°	**15°**	1.55	3.998	1.964
ö/74. sample	7.75	12.07	126°40'	**13°**	1.56	3.50	2.444
ö/37, CT	9.33	27.00	108°59.7'	**10°**	2.89	5.025	1.766
ö/37, sample	6.39	20.05	105°	**10°**	3.18	5.448	1.211
53.5.31, CT Szentes-Vekerzug	13.07	28.10	100°	**10°**	2.15	3.733	0.373
54.5.15, CT Szentes-Vekerzug	13.90 residue?	28.50	95°	**10°**	2.05	3.56	0.09
53.5.18, CT Szentes-Vekerzug	14.37	27.3	95°	**15°**	1.90	4.918	0.056
1309.24, CT Szentes-Vekerzug	10.9	23.10	92°28'	**15°**	2.12	5.487	0.015
60.13.48, CT Szentes-Vekerzug	13.23	27.70	110°	**15°**	2.09	5.409	0.945
61.37.20, CT Szentes-Vekerzug	11.97	22.20	92°28'	**15°**	1.85	4.788	0.013
60.13.67, CT Szentes-Vekerzug	11.93	21.40	115°	**15°**	1.79	4.632	1.235 The bone cortex is damaged
Csanytelek grave 71. mt. III. right, CT	17.40	28.90	115°	**15°**	1.66	4.30	1.146 Medullary cavity filled with residue
Csanytelek grave 71. mt. III. left, CT	14.90	27.10	105°	**25°**	1.82	7.69	0.288 Medullary cavity filled with residue

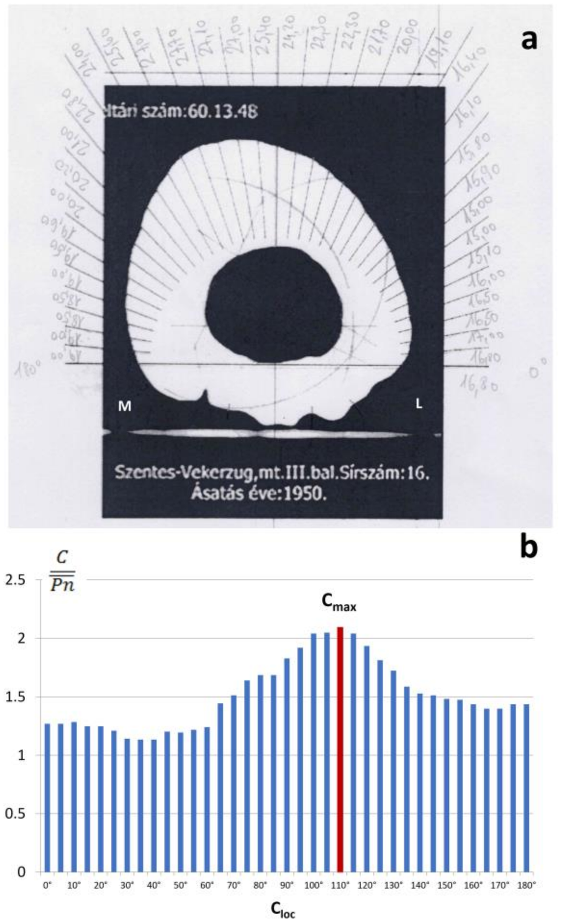

Fig. 10a-b.: a) Szentes-Vekerzug tomb No. 16, CT image of Scythian horse well preserved mt. III. (M: Medialis, L: Lateralis), b) Diagram of the load intensity, the place of C_{maxloc} and the load value are those of a riding horse

10a-b ábra: a) Szentes-Vekerzug 16. sír, szkíta kori ló jól megőrződött mt. III. CT képe (M: Medialis, L: Lateralis), b) A terhelés intenzitás diagramja, a C_{maxloc} helye és a terhelés értéke hátas lóé

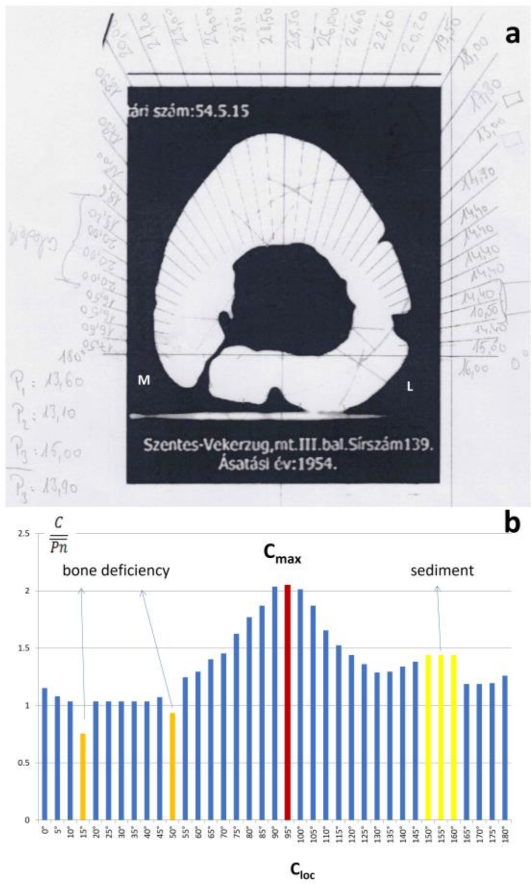

Fig. 11a-b.: a) Szentes-Vekerzug tomb No. 139, CT image of Scythian horse damaged metatarsus III filled with residue (M: Medialis, L: Lateralis), b) Diagram of the load intensity, the place of C_{maxloc} and the load value are those of a riding horse

11a-b ábra: a) Szentes-Vekerzug 139. sír, szkíta kori ló sérült, üledékkel töltött metatarsus III. CT képe (M: Medialis, L: Lateralis), b) a kéregállomány szélesség megoszlása, a C_{maxloc} helye és a terhelés értéke hátas lóé

Analysis of archaeological finds

The finds of two internationally known Scythian burial sites of determining importance, i.e. Csanytelek-Újhalastó (1 specimen) and Szentes-Vekerzug (14 specimens) (Galántha 1981, 1986; Párducz 1952, 1954, 1955) were used in the development of the non-destructive test method. The analysis of the archaeological bone finds of good retention ability did not cause any difficulty (**Fig. 10a-b**). However, in order to avoid pitfalls, taphonomic processes had to be taken into consideration as well. Remains go through taphonomic changes after being buried. In the images produced by using computed tomography several of these appear as disturbing image elements that may even make the testing impossible. Such include:

- insufficient cortex preservation
- cortex fracturing
- cortex warps
- inseparable residue filling

The partial or complete lack of cortex may cause a loss of information (**Fig. 11a-b**), fractures and warps may cause the shifting of angles. If the *canalis nutritium* is completely filled with residue it is difficult to position the image. In such a case, we can select the last image that still shows a sharp projected rear panel (T plastic back wall). In some other cases the medullary cavity is filled with soil or other residue (**Fig. 11a-b**). With some luck the filling may be distinguished from the bone cortex by using an image enhancement program, and in this case the measurement can be performed. If the residue cannot be distinguished from the bone, the measurement is partly or completely impossible

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based on the CT image. The result depends on the position and quantity of the residue. In order to minimise the loss of data, both metatarsi of the specimen must be examined, if possible. In the case of the presented example of Csanytelek (**Figs. 12a-b, 13a-b**) the deforming effect of the residue filling was reduced, and the information extracted from the two bones solved the question that would not have been answered by the data set of one or the other metatarsus separately.

The line bordering the cortex from the direction of the medullary cavity must also be monitored, as the projection of the trabecular system may appear on it in the form of a wavy line, which should also be considered when measurement is performed.

Evaluation of data

In the preliminary evaluation of the data presented here we mainly wanted to find an answer to the question to what extent the test results of the new archaeozoological method are similar to or differ from the image we developed during the research so far by using traditional methods through the morphological testing of the horse bones in light of the presence or absence of associated horse tackle.

Csanytelek-Újhalastó horse tomb No. 71.

According to the description of the excavator Márta Galántha, in the Scythian mixed-rite cemetery dated to the mid-6th and second half of the 4th century B.C., the skeleton of the horse lay in a kidney-shaped NW—SE oriented grave, with its legs pulled under itself. In her view the skull was not put into the tomb originally.

The fill of the tomb was heavily charred, and she also observed a thick layer of charcoal under the skeleton but did not find any grave goods (Galántha 1981, Image No. 10). In our opinion, on the basis of the new research results it is important to clarify one of the excavator's extremely important observations, i.e. that the horse, as she put it, was laid in the pit with its legs pulled under itself. It is well apparent on the image published that the end of the foreleg covers the hind leg (Galántha 1981, image No. 10), and neither a horse nor any other animals hold their legs in such a position under

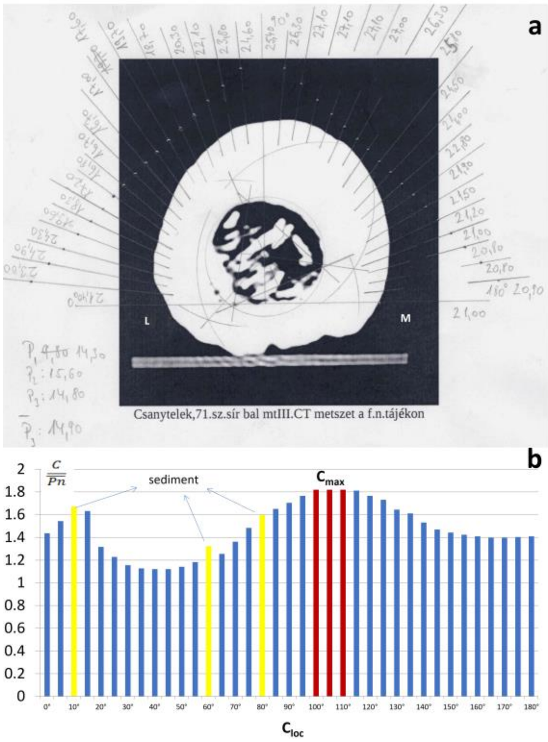

Fig. 12a-b: a) Csanytelek-Újhalastó tomb No. 71, Scythian horse left metatarsus III filled with residue CT image (M: Medialis, L: Lateralis), b) Diagram of the load intensity, the place of C_{maxloc} and the load value are those of horse which did not work

12a-b ábra: a) Csanytelek-Újhalastó 71. sír, szkíta kori ló üledékkel kitöltött bal metatarsus III. CT kép (M: Medialis, L: Lateralis), b) A terhelés intenzitás diagramja, a C_{maxloc} helye és a terhelés értéke a munkát nem végzett lóé

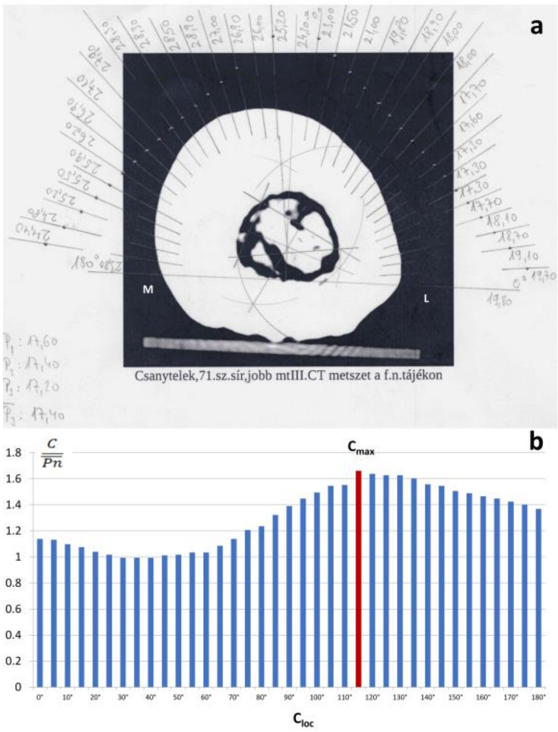

Fig. 13a-b: a) Csanytelek-Újhalastó tomb No.71, Scythian horse right metatarsus III filled with residue CT image (M: Medialis, L: Lateralis), b) Diagram of the load intensity, the place of C_{maxloc} and the load value are those of horse which did not work

13a-b ábra: a) Csanytelek-Újhalastó 71. sír, szkíta kori ló üledékkel kitöltött jobb metatarsus III. CT kép (M: Medialis, L: Lateralis), b) A terhelés intenzitás diagramja, a C_{maxloc} helye és a terhelés értéke a munkát nem végzett lóé

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natural circumstances. This condition is the result of human intervention, it is widely spread, and observable in the Scythian depiction of several animal species, clearly linked to sacrificial acts (Szabó 2019). This introduces a new and determinant viewpoint also in the archaeozoological investigations made so far. According to István Vörös, the animal was an old mare of medium height, 141.2 cm (Vörös 2010, 65). Considering the current analysis of the hypertrophic changes caused by work, the distribution of the cortex width, the place of C_{max} and the extent of load, the specimen was a horse that did not work (**Figs. 12a-b**, **13a-b**), which was also confirmed by the archaeological observations, that is the absence of harness.

Szentes-Vekerzug

Gábor Csallány carried out excavations at this site in 1937 and in 1941, continued by Mihály Párducz between 1950-1954. It is located north-east of the town of Szentes, along the Veker, a former left bank tributary of the river Tisza.

Szentes-Vekerzug tomb No. 11. (61.37.20) Tomb No. 11. was revealed as early as 1941 (Csallány & Párducz 1944-45, 107., XLV. t. 9—12.), but it was covered again, then in 1952 it was reopened (Bökönyi 1954, 99). An iron cheekbit was found in the horse’s mouth, buried lying on his right side, and according to István Vörös it was a mature stallion with a wither’s height of 130.9 cm (Vörös 2010, 54). Our tests showed that the place of C_{max} and the extent of load are those of a horse that did not work (**Fig. 7b, Table 1.**).

Szentes-Vekerzug tomb No.16. (60.13.48) The horse, laid on his right side with its legs hogtied, was placed in the pit with his head twisted back to the right. Near its ear, under its head, close to its mouth the remains of 4 bronze phaleras, covered with electron plates, and an iron bit were found (Párducz 1952, 147), which clearly suggests that the animal was buried bridled. István Vörös observed three-edged bronze arrowheads penetrating the III. cervical vertebra and the right scapula (Vörös 2010, 61) which may imply the manner of slaughtering the animal. Based on earlier analyses of the bones, significantly differing opinions evolved about its sex, age and body size, including allegedly a 5 and 5 and a half years old stallion with a wither’s height of 130-135 cm (Bökönyi 1952, 177-178) as well as data such 14–16 years of age and a withers height of 138.9 cm (Vörös 2010, 61). Based on our current tests, the well retained metatarsus III CT image, the distribution of the cortex width, the place of C_{max} and the extent of load are those of a riding horse (**Fig. 10a-b**). The new results also suggest that the harness parts found belong to the spectacular and valuable bridle of a riding horse. Determining the accurate age of the specimen will be important for clarifying whether a much-used, appreciated, but aged horse with an already reduced value of use was sacrificed.

Szentes-Vekerzug tomb No. 17. (60.13.67) The only artifact found with the horse, laid on its right side with its legs pulled up, was the fragmentary iron bit found in its mouth (Párducz 1952, 147). Sándor Bökönyi, who first examined the bones, observed deformations on the legs that may have caused lameness. Unfortunately, the sex, age and body size data, according to which the animal was a 4-years-old mare of 120-125 cm withers height (Bökönyi 1952, 178.), also differ from the subsequent identification, according to which the horse with a withers height of 136.4 cm was approximately two years old, but its sex could not be determined (Vörös 2010, 61). Our tests showed that the data measurable based on the CT image of the metatarsus III filled with residue, the place of C_{max} and the extent of load are those of a horse that did not work (**Fig. 14a-b**).

The marks suggesting that the specimen was lame imply that the animal did not have a significant value of use, and its simple bridle did not have valuable metal decorating elements either (Bökönyi 1952, 177).

Szentes-Vekerzug tomb No. 22/I. (1309.24) There were two horses in the pit, with their heads turned in the same direction, and with their backs turned towards each other, out of which the mare on the East side, laid on its left side was allocated number I. The excavator observed burn marks at the bottom of the pit, the charcoal layer was especially of significant quantity (5-8 cm thick) in the area of the skulls and the hind legs, which caused the bones to be heavily burnt. In the mouth of horse No. I, the remains of an iron bit were found and an iron knife laid on its pelvis (Párducz 1954, 22). Based on the traces of periostitis observed on the right metatarsus, this specimen was also thought to be lame (Bökönyi 1954, 94-96).

In the course of previous and more recent investigations, significant differences appeared in this case also regarding the sex and age, and in addition to being a mare of 5 and a half years (Bökönyi 1954, 94) this horse was also thought to be a 14–16 years old mare, with a wither’s height of 135.3 cm (Vörös 2010, 62). Based on the data derived from the horse’s metatarsus III CT image, the distribution of the cortex modified by the projection of the bone framework, the place of the C_{max} and the load value were those of a riding horse (**Fig. 15a-b**), which is also confirmed by the horse’s bridle. The marks suggesting that the specimen was lame imply that the animal did not have a significant value of use.

The joint burial of the two horses was earlier thought to be attributable to the fact that they were a pair of cart horses (Bökönyi 1954, 96). This is clearly refuted by the current work-related hypertrophic test results.

Szentes-Vekerzug tomb No. 32. (53.5.18). No finds were revealed around the horse placed in the pit on its stomach that belonged to its bridle. Its right shinbone (*tibiae*) and the inner part of the foot got burnt (Párducz 1954, 32; Bökönyi 1954, 96). This is the skeleton of a stallion of approximately 6-7 years (Bökönyi 1954, 96). Horse tomb No. 32. The horse, oriented in an N-S direction, is lying on its stomach, collapsed. Its head is set on its nose-mouth. Both tibiae are broken. It was a young 3½–4 years old stallion with a wither's height of 134.6 cm (Vörös 2010 62). Based on our examination, the place of the C_{max} and the load value were those of a non-working horse (**Fig. 6a, Table 1.**).

Szentes-Vekerzug tomb No. 36. (53.5.31) The horse was put in the grave with an iron bit in its mouth, with its legs collapsed and lying on its stomach, and a dog was put at its feet (Párducz 1954, 33). His skull shows the marks of a strong blow by a blunt object (Bökönyi 1954, 96-98). The specimen was a stallion around 4 years old, with a wither's height of 129.4 cm (Vörös 2010, 62). The CT image of the metatarsus III reveals that the *canalis nutritium* is filled with residue, the place of the C_{max} and the load value were those of a riding horse (**Fig. 16a-b**), an observation which, from the archaeological point of view, is congruent with the discovery of cheek bits. The mark of a blow on the head with a blunt object, which only numbed the animal but did not kill it, is also interesting as this process essentially served the same purpose as hogties: the large animal was immobilized and could then be easily bled to death.

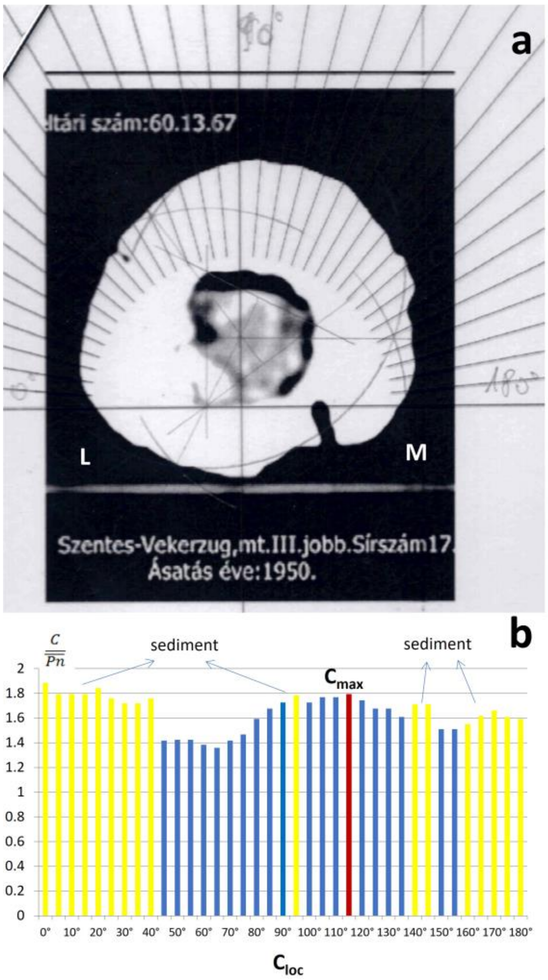


Fig. 14a-b: a) Szentes-Vekerzug tomb No. 17, Scythian horse, metatarsus III filled with residue CT image (M: Medialis, L: Lateralis), b) Diagram of the load intensity, the place of C_{maxloc} and the load value are those of horse which did not work

14a-b ábra: a) Szentes-Vekerzug 17 sír, szkíta kori ló, üledékkel kitöltött metatarsus III. CT kép (M: Medialis, L: Lateralis), b) A terhelés intenzitás diagramja, a C_{maxloc} helye és a terhelés értéke a munkát nem végzett lóé

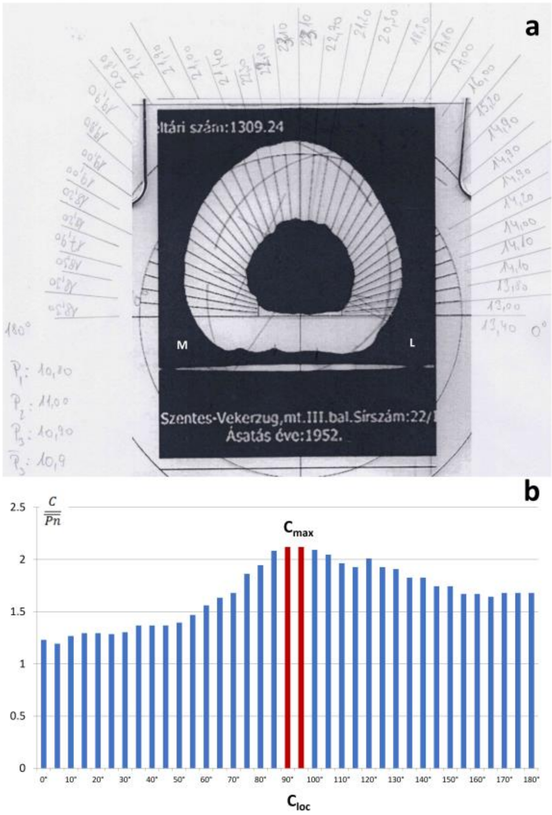
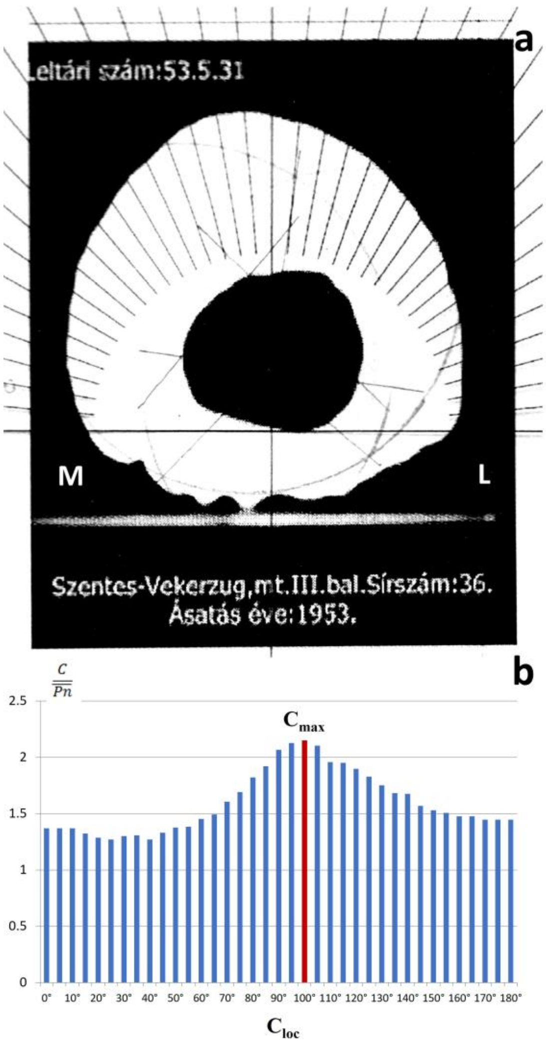


Fig. 15a-b: a) Szentes-Vekerzug tomb No. 22/I, Scythian horse metatarsus III CT image with bone framework (M: Medialis, L: Lateralis), b) Diagram of the load intensity, the place of C_{maxloc} and the load value are those of a riding horse

15a-b ábra: a) Szentes-Vekerzug 22/I sír, szkíta kori ló metatarsus III. CT képe csontgerendázattal (M: Medialis, L: Lateralis), b) A terhelés intenzitás diagramja, a C_{maxloc} helye és a terhelés értéke hátas lóé



Figures 16a-b: a) Szentes-Vekerzug tomb No. 36, Scythian horse metatarsus III CT image, *canalis nutritium* filled with residues (M: Medialis, L: Lateralis), b) Diagram of the load intensity, the place of C_{maxloc} and the load value are those of a riding horse

16a-b ábra: a) Szentes-Vekerzug 36 sír, szkíta kori ló metatarsus III. CT kép, üledékkel kitöltött *canalis nutritium* (M: Medialis, L: Lateralis), b) A terhelés intenzitás diagramja, a C_{maxloc} helye és a terhelés értéke hátas lóé

Szentes-Vekerzug Tomb No.139. (54.5.15) A dog was also placed at the hind legs of this horse laid on his right side with his legs bent. Three bronze phaleras were found around the head, and an iron bit was discovered between the teeth (Párducz 1955, 8-9). The withers height of the 5½–6 years old stallion was 134.8 cm (Vörös 2010, 62). Based on the CT image of the injured metatarsus III filled with residue, the distribution of the cortex width, the place of the C_{max} and the load value are those of a riding horse (**Figs. 6b, 11a-b**), which suggests that the ornate bridle was indeed used during riding.

The specimens in tombs 11. 17., 32. (Inventory numbers: 61.37.20; 60.13.67; 53.5.18) of Szentes-Vekerzug did not work extensively (C_{maxloc}: 92, 115, 95; load: 1.85, 1.79, 1.90), they were kept on pasture, and there could have been a sufficient amount of feed and water. They were given more substantial environmental load than the recent animals kept on pasture, available in the comparative material, and their load is in the same group as that of the average Pleistocene wild horses. They are likely to have lived their lives between alternating pastures, within a radius of a few kilometres. It is highly likely that no permanent or frequent compelling events occurred in their lives that would have made them cover substantial distances. The animals in tombs No. 16., 22/1., 36., 139. (Inventory numbers: 60.13.48., 1309.24., 53.5.31., 54.5.15) at Szentes-Vekerzug were riding horses (C_{maxloc}: 110, 92, 100, 95; load: 2.09, 2.12, 2.15, 2.05).

According to their load values they could have served their masters in areas adjacent to human settlements, living a peaceful everyday life. They were not substantially loaded in long distances. The information derived from the bones used in the methodological study reflects the impression of a calm, peaceful life in the Scythian age in Szentes-Vekerzug (**Table 1.**).

The metatarsi of the same specimen of the Csanytelek tomb No. 71. are filled with residue, and the examination of the two bones provide information that may be evaluated together. The specimen could have been in its early middle age, not used for work and slightly loaded. It is likely to have spent its life in the close vicinity of human settlements and did not take part in major change of pastures. In the case of Csanytelek the little and slightly uncertain information does not allow to draw additional conclusions.

Summary

The suitability of images produced in a non-destructive manner for conducting work-related hypertrophic tests has been confirmed in practice by the test results of the Scythian horses of Csanytelek-Újhalastó and Szentes-Vekerzug. In the case of Csanytelek-Újhalastó the archaeological observations and the results of the work hypertrophic tests support each other, that the horse carefully arranged in the pit dug among the graves of the mixed-rite cemetery without additional artefacts in a may have been a hog-tied animal, functioning as a ritual kill, a sacrifice. The selection of an old mare also confirms that, as a trained horse capable of work this individual may have represented significant value. A good example for that is horse No. DTQ83 from the late Roman cemetery of Dombóvár-Tesco, which was also a specimen unsuitable for work despite the remains of its saddle and bit (Bozi & Szabó 2020, 82-83).

In the analysed material of the Szentes-Vekerzug Scythian cemetery it was observable that they used less valuable in practice, not working (tomb No. 17), or possibly injured horses (tomb No. 17., 22/I.) for sacrifice. The data show that the reduced utilitarian value can be presumed even in the case of riding horses in their prime buried with an ornate bridle, but injured, or older riding horses (tomb No.16) that used to be valuable. The work-related hypertrophic tests also proved that in tomb No. 22 of the Szentes-Vekerzug Scythian cemetery, though a pair of horses was buried, they were not two carriage-pulling horses placed next to each other, but selected according to their roles in the sacrificial act and not based on the way they were used. In light of the burnt residue and the charcoal remains found around them (also known in the burials of Iranian people), they are closely related to the Csanytelek sacrificial pit. However, the different way of laying the animals calls attention to the fact that within the general practice attached to the elements of customs there might be slight differences on the level of the extended families or kin groups. Several examples could be observed of this phenomenon in the case of the Caucasian Ossetes, where even up to now the circles of the various level community and family celebrations are well distinguished, which determines in the first place the species of the sacrificial animal to be chosen, and the criteria of its selection (Szabó 2018; 2019). Practice shows that the viewpoints of representation are given increasing emphasis parallel to the significance of the community celebrations, while in the case of family celebrations reasonability and cost-efficiency are more relevant. This is reflected in the current test results, when in a number of cases demonstrably such horses were killed for the sacrifice whose use value was lower, did not perform work, or was older, or possibly injured.

The material of the two Scythian cemeteries under review reflects well that the previously developed method of analysing the work-related hypertrophic deformation of horses and practically all equida metatarsus III bones and the analysis of CT scans (a non-destructive method) provide a rich repository of data. They not only help interpreting the archaeological finds, but also facilitate posing additional questions from new perspectives and provide adequate answers.

Acknowledgement

The reported study *"Riding and cart horses in the archaeological cultures of the Eurasian steppes in the XX-III cent. BC (on materials of horse equipment and archaeozoology)"* was funded by RFBR and FRLC, project number 21-59-23003. Leader of the project "Верховые и упряжные лошади в археологических культурах степей Евразии в XX-III вв. до н. э. по материалам конского снаряжения и археозоологии" winner of the tender of the Russian Foundation for Basic Research, to be implemented between 2021-2023 and of the Russian research group: Sulga, Pjotr Ivanovics, head of the Hungarian research group: Szabó, Géza, members: Koszincsev, Pavel Andrejevics - Sulga, Daniil Petrovics - Bozi, Róbert - Horváth,Veronika.

We would like to thank Dr. Gábor Tomka, Directorate General of the Hungarian National Museum, for being helpful and permitting to research of the Vekerzug Scythian horses, Annamária Bárány archaeozoologist for preparing the samples and for her generous assistance, Gábor Bomba and Márk Szauer, staff of the Szekszárd Spirit for the MR scans, Dr. Gábor Szigeti owner and chief veterinarian of Vezér Veterinarian Centre for making their CT equipment available and for his active participation in producing the scans, and Árpád Bozi for producing the photos of the measuring process. We also thank Márta Galántha, Farkas Márton Tóth and Edit Király archaeologists for their help in being able to examine the Csanytelek finds, Éva Gömöri for the English translation and László Bartosiewicz, Zoltán Kis for their helpful advice.

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Appendix 1: Positioning the test material, producing the sectional image
https://drive.google.com/file/d/1xhCJqKAIpCeT_6ceYd90UbNQWH-5A2LF/view?usp=sharing

Függelék 1: A vizsgálati anyag előkészítése a méréshez, a metszeti kép elkészítése
https://drive.google.com/file/d/1xhCJqKAIpCeT_6ceYd90UbNQWH-5A2LF/view?usp=sharing