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ORIGINAL ARTICLE

Virtual unwrapping of the *BISPEGATA amulet*, a multiple folded medieval lead amulet, by using neutron tomography

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Abstract

In recent decades, computed tomography (CT) combined with suitable image processing software has become a valuable tool to enable the reading of texts written on scrolls, which are fragile, damaged, or fused together, without physically unwrapping them. X-ray based computer tomography has successfully been used on scrolls made of soft materials such as papyrus and parchment. Although in few cases inscriptions on thin metal plates that have been rolled up and worn as amulets have been deciphered by using a high energy X-ray source, the readability of writings on of metal scrolls is limited by the high attenuation factor of this type of material.

In this paper, we present for the first time the use of neutron tomography as an alternative to X-ray tomography for studying hidden inscriptions on folded metal objects. It is shown that the method overcomes the limitations of X-ray tomography caused by high attenuation of X-rays in lead objects.

The inscription on the medieval Bispegata amulet, unearthed during excavations in Oslo's Old Town, has been read by using neutron tomography combined with VG Studio software. The amulet was made up of a thin lead sheet with an inscribed text, folded together into a rectangle. The inscription was runic, containing words of religious and magic meaning.

KEYWORDS
Lead amulet, medieval Scandinavia, neutron tomography, runic inscription

INTRODUCTION

Extant writings give us insights into life and thinking in past times. They do not, however, cover all parts of society and all views of life. Regarding religious ideas in medieval times, we have a good insight into the established theological conceptions while our knowledge on the religious beliefs of common people is still incomplete. A particular group of objects may here contribute to filling our lack of knowledge: amulets containing short texts with religious, magical, or apotropaic content. Those amulets mirror beliefs and ideas on the supernatural world that are not necessarily in accordance with the official dogmata.

Textual amulets are found throughout Europe and may be made of various materials such as metal, wooden sticks, paper, and parchment (Muhl & Gutjahr, 2013; Skemer, 2006). We find amulets on various material artefacts in Scandinavia as well, though the lead amulets have the longest inscriptions. Among the Scandinavian countries, Denmark has the most extensive and systematic research on inscribed lead amulets in recent years (see Imer, 2021; Imer & Steenholt Olesen, 2018; Imer & Stemann-Pettersen, 2016). Like the present amulet, many lead amulets in both Norway and Denmark are found folded, and in Denmark, several folded amulets have been physically opened so that it is now possible to read all the still legible text on these amulets (Imer & Steenholt Olesen, 2018; Imer & Stemann-Pettersen, 2016). This has taught us much about how the amulets were folded and also that hiding the text seems to be part of the practice connected to these amulets. As Imer and Steenholt Olesen (2018): 125) writes, "[t]he power of the written word was to be preserved and protected to gain more power." The same view is expressed by Muhl and Gutjahr (2013: 58) concerning the German amulets.

The Danish research (Imer, 2021; Imer & Steenholt Olesen, 2018; Imer & Stemann-Pettersen, 2016) gives us information about what kinds of inscriptions were commonly found on lead amulets in Scandinavia. Both internationally and in Scandinavia, interpreted lead amulet inscriptions generally have some form of religious content. This applies both to runic and Roman alphabetic amulets (see e.g. Imer & Steenholt Olesen, 2018). Moreover, the text is usually in Latin, also in Scandinavia (Imer & Steenholt Olesen, 2018: 153–54). We have no similar overview over Norwegian lead amulets, though the *Scandinavian Runic-Text Database* (1993), which is not updated with the most recent finds and neither contains Roman alphabet inscriptions, records 27 lead artefacts with runic inscriptions. Most of these have probably functioned as amulets. Of the 27 amulets in the database, 21 have more or less legible inscriptions, which range from faultless Latin to a mix of Latin and nonsense phrases to meaningless sequences of runes and rune-like symbols. None has text in the vernacular.

THE ARCHAEOLOGICAL CONTEXT

The amulet presented in this study was unearthed in 2018 during excavations conducted by *The Norwegian Institute for Cultural Heritage Research* (NIKU) in Oslo's medieval town (Berge et al., forthcoming). Under today's *Bispegata*, a street connecting Oslo's Old Town with the modern Barcode skyline, the archaeologists uncovered its medieval predecessor *Bispeallmenningen*, a street made of wooden timbers. The medieval street name means 'the bishop's street for common use' and connected the religious center of medieval Oslo with the harbor. The excavation also uncovered parts of the bishop's residence, the remains of secular timber, and stone buildings and a rich collection of various objects and features, from daily life objects to luxury goods. Among them was our lead amulet, sized 27 × 22 × 6 mm, found between the timbers of the wooden street. After careful cleaning, it was found to be a lead sheet, covered with runes and folded several times, so that it now exhibits an almost rectangular shape (Figure 1). Its inscription and shape led to the assumption that the object was worn as an amulet. The sketch in Figure 2 shows how the lead sheet was folded.

The *Bispegata amulet* dates to ca. AD 1300. As most amulets are single finds without context, which can solely be dated on basis of the inscription, the exact dating and find context give the *Bispegata amulet* a particular importance. The site was excavated in stratigraphical sequences, using the *single context* recording method (Harris, 1989). The method ensures a stratigraphic sequence of every layer and feature, and the amulet was dated by the soil layer of which it originated, a layer between two generations of street pavement. The underlying pavement of the amulet's origin was ^{14}C-dated to AD 1224–1,237 (8,5%) /AD 1240–1,284 (86,8%) (2 sigma, UBA-39849). However, because the timber is believed to have been reused, and the previous generation of pavement was dendrochronologically dated to around 1,290, the soil containing the amulet is believed to have been deposited closer to the year AD 1300.

In AD 1300, Oslo covered a small piece of land on the east side of Bispevika bay. Urban settlements in this area were initiated in the early 11th century but expanded quickly in the 13th century and first half of the 14th century. Toward the middle of the 14th century, the expansion also came in the form of densification, because the increase in population demanded a better utilization of plot areas (Nedkvitne & Norseng, 2000:103–104). Oslo's position as capital seems to have been fixed during the reign of Håkon V Magnusson (r. 1,299–1,319), and it has been suggested that around this time, Oslo had a population of around 3,000 adults

FIGURE 1 Object photos of the *Bispegata amulet*.
Notes: Roughly one third of the front side is visible. Photo: Kirsten Jensen Helgeland/MCH

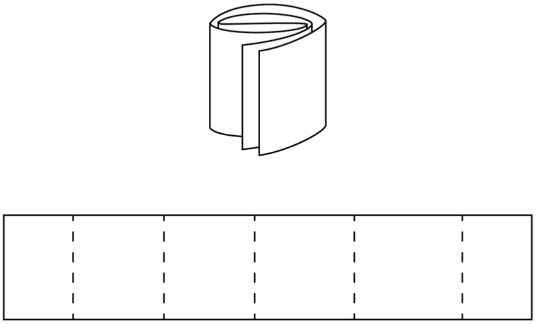

FIGURE 2 Sketch of how the object is folded together
Note: Illustration: Ingvild Tinglum Bøckman

(Schia, 1995:151). Other high status finds from the same excavation shed light on our amulet. In addition to more common objects like leather shoes and imported pottery, finds included gold threads, gold and silver fittings, amber pearls, decorated leather objects, a wax tablet, and decorated ivory (Berge et al., forthcoming). The dumped material also contained other objects with runic inscriptions: a wooden toy boat, a small whetstone, and a wooden bowl (Ødeby, 2020).

The medieval town is in a different location from today's city center. After a fire destroyed the town in 1624, King Christian IV demanded that the town was to be rebuilt a kilometer westward, leaving the area of the old town to decay and later to act as a supply area. In the 20th century, the area became a traffic hub; and during the building of new train lines, large areas of the old town have been, and are still to this day, excavated by archaeologists.

VIRTUAL UNWRAPPING: CHOICE OF METHOD

Mechanical opening of folded lead amulets changes the characteristic appearance of the artifact, is in most cases not reversible, and may damage the object, depending of its condition. Therefore, a non-destructive alternative method to study the inscriptions scratched into the metal, is highly desirable.

X-ray computed tomography (CT) has become a widely used tool to virtually unwrap folded or rolled historical documents. It was successfully applied to scrolls made of papyrus and parchment, as, for example, in the cases of the carbonized and highly fragile scrolls from the *Villa of papyri* at Herculaneum (Stabile et al., 2021) and the Elephantine papyri (Mahnke et al., 2020). The visualization of the letters, however, remains very challenging due to the use of carbon ink, which exhibits very low contrast to the supporting material. Writings with iron gall ink provide a higher density and contrast, and could be disclosured, as demonstrated by Rosin et al. (2018) in the case of the Bressingham scrolls and for the En-Gedi scrolls (Seales et al., 2016).

Also inscriptions scratched into thin silver sheets, which were folded afterwards and beard as an amulet, could be read (Barfod et al., 2015) However, the method finds its limitation when it comes to thicker metal sheets, in particular those made of lead. The high attenuation of lead prevents X-rays from penetrating lead objects.

There are only two cases of virtually unwrapped folded lead amulets reported in literature:

One of them describes the partial reading of a Mandean scroll dated to the fifth century AD. The scroll contained 99.5% lead. Because the letters were scratched into the metal with a deepness of only 30 micrometers, a high resolution was required. The object needs to be placed close to the X-ray source, and the beam size must be in the micrometer range. Due to corrosion, only parts of the text written in the outer layers could be read. It contained incantations, and also mentions the name of the owner, Dasnaya (Neuber & Reinhart, 2012).

Another successful reading was recently reported by Vavřík et al. (2020). A lead amulet folded like a little booklet was found in Dřevíč fortress in Central Bohemia. A palaeographical analysis led to a dating to the first half of the 12th century. The outer layer was corroded and damaged. To achieve a signal-to-noise ratio sufficient to conduct tomography, a high energy X-ray source was used. However, as the authors reported, the high tube voltage resulted in increased X-ray scattering and in a large emission spot on the object, resulting in blurred projections and decreased image resolution. To reduce the negative impact of these effects, a couple of measurements regarding both experimental set-up and data processing were taken (Vavřík et al., 2020).

Due to the high attenuation of lead, an X-ray tube with voltage and current as high as possible has to be used. However, the high voltage leads to an increasing scattering of X-rays in the metal, which results in a more blurred image (Vavřík et al., 2020).

To overcome the difficulties related to X-ray tomography on lead objects, we decided to use neutron tomography to investigate the Bispegata amulet. The method works along similar principles as X-ray tomography but provides complementary information. The attenuation of X-rays increases with the atomic number, which means that heavy elements will attenuate X-rays to a greater extent than lighter elements, which are more easily penetrable. Neutrons, on the other hand, show different, partially complementary, behavior: Some light elements such as hydrogen show high contrast for neutrons, whereas some heavy elements such as lead show high transparency.

EXPERIMENTAL

An initial elemental analyses using the handhold X-ray fluorescence spectrometer Tracer 5 by Bruker confirmed that the object consists of lead. A detailed analyses of a small sample taken from the object was performed using a FEI Quanta 450 scanning electron microscope equipped with an Oxford system for energy dispersive X-ray spectroscocopy (SEM/EDS). The metal was identified as pure lead. The object is covered with a black corrosion layer, clearly visible in the SEM image, which consists of lead and sulphur.

The neutron tomography experiments were carried out at the neutron imaging instrument ICON (Kaestner et al., 2011) at the Paul Scherrer Institute (PSI), Villigen (Switzerland). The instrument is fed by the spallation neutron source SINQ (Blau et al., 2009) with neutrons in a cold spectrum. As detector system, a scintillator-digital camera system was used with a fixed field of view of 27 mm $\times$ 27 mm. The camera was an Andor iKon-L with 2048 $\times$ 2048 pixel. The resulting pixel size was 13.5 µm/pixel. As scintillator a 20 µm thick gadolinium oxysulfide scintillator screen was used. The spatial resolution, which can be achieved with this setup, is in the order of 30–50 µm. For the tomography, 575 projections over a range of 360° were acquired. The exposure time per image was 90s. The reconstruction of the tomography was carried out using the software Muhrec (Kaestner, 2011). To reduce the noise in the reconstructed data set, the tomography slices were subsequently processed with the software Kiptool, which was developed at PSI (Carminati et al., 2019). The filter algorithm used, was an implementation of an edge-preserving smoothing inverse scale space filter described by Burger et al. (2006). The reconstructed tomography data were then virtually unfolded using the software VG Studio max 3.2 by Volume Graphics. For this, the non-planar view module was used; by positioning numerous height marks in the 2D sections through the volume data set, it was possible to generate a non-planar view of the surface of one folded segment of the amulet. The surface of the lead sheet is covered with a higher attenuating film, probably due to higher hydrogen content and visible as a white layer in the CT data; the high contrast between this layer and the void between the layers was used to position the mentioned height marks. This procedure was repeated for every surface within the folded amulet (Figure 3). The only regions where this failed was in the sharp bends, where the material was tightly folded. Here, it was not possible to virtually unfold the amulet and extract useable images (Figure 4).

The inscription on the *Bispegata amulet*

The following section will present the runic inscription on the amulet, illustrated in Figure 5. When rendering the runes on the amulet, bold typeface is used. A bow above two characters indicates that the characters are bound together and share a stave. Characters with a dot underneath are uncertain. Single slashes indicate an uncertain rune with more than one possible interpretation.

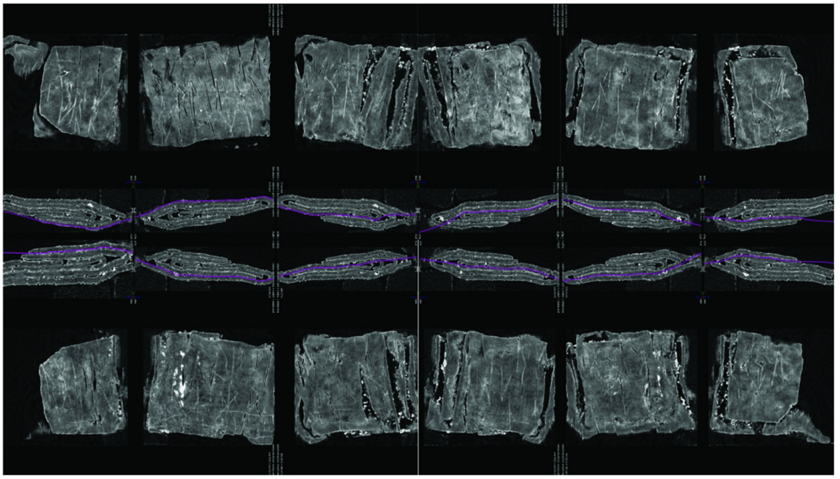

FIGURE 3 Non-planar images of every surface of the folded amulet, arranged in order
Notes: The purple lines indicate how the different layers were defined in data processing. Data processing: David Mannes/PSI. Arrangement: Kristine Ødeby/NIKU

FIGURE 4 A reconstruction of the unfolded amulet based on cut-outs from the non-planar images in Figure 3, with additional cut-outs of the photographs in Figure 1, of the folded object's visible surfaces
Note: Illustration: Kristine Ødeby/NIKU

The front side (see Figure 5) holds a Latin inscription written with runes with religious contents, and line 1 of the inscription opens with a word in Greek: *Tetragrammaton*. This is a name for God, meaning "the four letters", a reference to the Hebrew spelling *JHVH*. This word also appears on two other runic lead amulets from Norway: a cross from Madla near Stavanger (N 248; N + number refers to inscriptions published in *Norges innskrifter med de yngre runer*) and a plaque from Borgund in Sogn (N A5; N A + number refers to unpublished inscriptions from Norway). After *Tetragrammaton*, an uninterpreted sequence of runes follows; then, near the end of line 1, we have the sequence **o͡ṇla͡uṣs a͡k/æ nt͡us**. This could tentatively be interpreted as *Olavus sanktus*. Such an interpretation fits well with known content from other textual amulets, as references to saints are not uncommon. The interpretation of the first part as *Olavus* is nevertheless uncertain as the name is not spelt with an *n* in this way in other contemporary sources (see Lind, 1905–15:cols 810–14). However, the **l** and **n** runes are quite similar, distinguished only by the height of the right branch, so a spelling **o͡lla͡us** may have been intended. Spellings of the name with double *l* are also rare, though not unheard of. Finally, we are likely to find the word *sator* at the end of line 1. The word is known from the palindrome *sator arepo tenet opera rotas*, which can be written in a square and read in all directions. This palindrome is

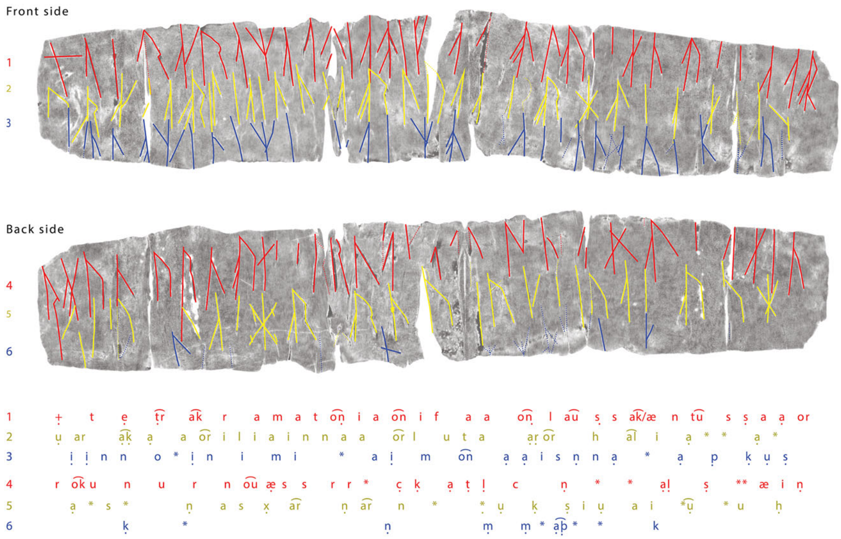

FIGURE 5 Visualization of runic inscription with transliteration
Note: Illustration: Kristine Ødeby/NIKU

well-known from amulets across Europe (cf. Skemer, 2006:116), though here, we have only the first word, which, standing alone, means "sower" in Latin.

Line 2 appears to be without linguistic meaning, though the runes are not carved randomly. The vowel **a** is frequent in this line, and the sequence **ao͡r** is repeated twice, although a variant is also found in the same line: **aạs o͡r**. These might be considered repetitions over the word *sator* from line 1 above. Repetitive phrases of various kinds are known from several Norwegian lead finds (see e.g. N A1, N A121, N A122, N A123, N A157) and may have been thought to have a magic effect. At the same time, the repetitiveness adds auditory qualities to the amulet text.

In line 3, the runes are less carefully cut than in the two lines above, but it seemingly opens with the Latin phrase *in nomine*, meaning 'in the name of'. After this, we could, perhaps, expect something like *patris et filii et spiritus sancti* as this is a well-known Latin Christian phrase. The continuation here cannot be anything as ordinary as that, however, as the following runes do not support such an interpretation.

Moving to the back side, the runes seem less carefully cut, and the text appears not to have any linguistic meaning. As there are several runes with an uncertain reading on this side of the amulet, we cannot rule out that parts of the text had lexical meaning. However, several Norwegian amulets have nonsense inscriptions (see e.g. N A1, N A2, N A121). Moreover, the views of the back side have revealed a rare rune shape in line 5: the **x** rune (see Figure 6). This rune is never used for carving in the vernacular; it is reserved for inscriptions in Latin language, and even here, the **x** is often avoided by using spellings such as **hs** or **ks** instead. In other instances, the form "X" is taken directly from Latin script. Another alternative, chosen for this inscription, is to modify an existing rune to denote **x**; here, an **h** rune is altered. The **h** rune is probably chosen due to its proximity to the Roman alphabetic "X" (for further discussion of the shape, see Dyvik, 1988:1–2 and Seim, 1988:19). This modified **h** used for **x** is very rare, and to our knowledge, it only occurs in four other inscriptions in the Scandinavian material (Zilmer, 2019, personal communication), three from Bergen, Norway (N B378, N B582, N B596; N B + number refers to unpublished inscriptions from Bergen), and one from Lom, Norway (N A77). This amulet gives us a fifth attestation from Oslo.

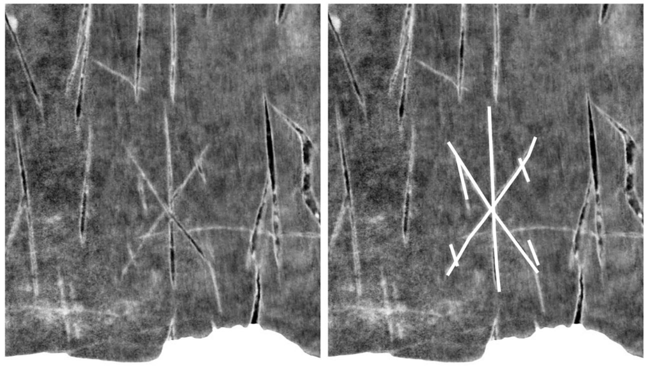

FIGURE 6 The X-rune in line 5, without (left) and with (right) tracing
Note: Illustration: Kristine Ødeby/NIKU

For each folded layer of the amulet, several viewing planes, or sections, were generated in different distances from the respective layer surface. The information from different depths, that is, different distances from the respective layer surface, has proven very useful for the runological analysis as this has revealed more information about each rune, such as their respective cutting depth. Moreover, the more shallowly cut runes do not appear in all the viewing planes, so more sections increase the chance of seeing all the runes. Finally, the metal has some folds and bends, with the result that the runes also appear clearly at different depths of each amulet fold. More viewing planes reveal greater detail about these bends and about the runes hidden in and on the various layers.

The CT slices from different depths, that is, different distances from the respective layer surface, also tell us that the runes appear to be carved in a slightly more haphazard way on the back side. Although the runes on the front side appear in three lines and only become more scattered toward the end of the amulet, the size of the runes on the back side varies more, and they are not as linear. At times, this leaves doubts about to which line a particular rune or part of rune belongs. There is also less room on the back side for line 6, that is, the third line on this side. There is clearly such a line, but the runes here are short and scattered. This indicates that the carver has put more effort into the carving of the front side, which constituted the outside of the amulet. This, in turn, may tell us something about the use and production of the amulet. As the outside is neater than the inside, the inside was most likely never intended to be read or seen, and the amulet was probably folded before it was sold, or at least before the buyer had time to read the inside and discover that its contents were without linguistic meaning. At the same time, the elegant appearance of the outside combined with the use of actual Latin words and not only nonsensical text indicate that this side was intended to be seen and read. This is in contrast to some Danish amulets that have no visible text on the outside (see e.g. Imer, 2021:25), and it shows that the practices connected to amulet production and usage were varied also within Scandinavia.

From the Latin phrases on the front side of the amulet, we may also deduce that this amulet, like the other lead amulets found both in Norway and Europe, had a religious function. From other amulet texts, we also know that the amulets were generally meant to protect the owner of it. Though we cannot establish this with certainty for the present amulet, it is likely that it had such a function.

Finally, we may conclude that the amulet was probably not carved by someone literate in Latin, as carving Latin phrases does not take much more time than carving meaningless letters if you know the Latin phrases by heart. What takes most time is the carving itself, the careful sliding of a knife through metal. The carver must have known some Greek and Latin, as words and phrases from these languages appear on the amulet, but these phrases could have been picked up by anyone who was regularly attending mass. That carvers used the Latin they picked up as participants in a Christian society is well attested from the Norwegian medieval runic material, which displays varying degrees of Latin literacy (see Knirk, 1998:489–494 for further discussions).

CONCLUSION

Neutron tomography has proved to be a powerful alternative to the still widely used mechanical opening of folded metal amulets and also to X-ray tomography that exhibits a number of backlashes due to the high attenuation of lead.

It was possible to decipher most of the text, though reading letters that are situated at curves and bends in the metal still remains challenging. We found that the entire amulet was carved with runes, not only on the outside layer. We can also be certain that there are no Roman alphabetic sequences on this amulet, though we know that some amulets use both Roman alphabetic script and runes (e.g. N 263 from Bru in Rogaland). Finally, we can interpret parts of the text, and from this, we know that sequences of nonsense intermingle with Latin and Greek on the amulet. The interpretation also confirms that the amulet, like other amulet finds from across medieval Europe, is likely to have had a magic–religious function.

The study of medieval amulets by using neutron tomography will be continued, with the aim to improve the technical methodology as well as the interpretation and to get a deeper insight into the medieval unorthodox beliefs.

PEER REVIEW

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