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FUNCTION AND MEANING OF A METALPOINT DRAWING BY JAN VAN EYCK

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ABSTRACT A technical study was carried out on a hitherto unknown Eyckian drawing. This drawing is clearly related to the left wing of Jan van Eyck's *Diptych with Crucifixion and Last Judgement*, in the Metropolitan Museum, New York. It is argued that the drawing has had a specific function in the genesis of the painting. In both works, the artist similarly demonstrates his ability to attend to detail without losing command of the general arrangement. Both works show, in spite of all the details, the same measure of coherence and organisation. The characteristics of the present metalpoint drawing are discussed in comparison with those of accepted Eyckian paintings. The object was first examined with the stereomicroscope, a high-resolution digital microscope, energy dispersive micro X-ray fluorescence (μ-XRF), X-ray diffraction (XRD), fibre optic reflectance spectroscopy (FORS), infrared reflectography (IRR), and digital imaging. Based on careful observations a small number of microsamples were taken to investigate the composition of the support and ground layer. The samples were analysed with various microscopic, spectrometric and chromatographic methods to further characterise inorganic components, fibres and organic substances. Most of the drawing was made with, at least, two different styluses. One type of lines was made with a silverpoint; other lines were made in goldpoint. In both cases the metalpoint lines were not made with the pure metals but with alloys, and efforts were made to quantify the alloy compositions. The results of these analyses are evaluated in relation to contemporary technical sources. Thus we hope to provide material for a proper assessment of the relation between painting and drawing, to address questions of attribution, and to shed more light on the process of transmission of motifs and ideas in Jan van Eyck's environment.

Introduction

Jan van Eyck was arguably the most significant individual artist of the Middle Ages. One of his most important, but also enigmatic, early paintings is a *Crucifixion*, now in the Metropolitan Museum of Art in New York (Figure 1). That *Crucifixion*, together with a *Last Judgement*, makes part of a small but impressive diptych. Both paintings have been the subject of extensive speculation on the formation of Van Eyck's style and pose considerable problems of attribution, which centre primarily on the *Last Judgement* wing. There is now general consensus that the *Crucifixion* part is an autograph work by Jan van Eyck.[1]

The panel with the *Crucifixion* has, however, been heavily discussed in terms of its original pictorial source(s). The imagery of the *Crucifixion* seems to be embedded in a tradition of images, that itself may find its origin in Franco-Flemish manuscript illumination. The origin of the pictorial language on the New York panel is often claimed to derive from the crucifixion images in the *Très Riche Heures* of Jean, Duke of Berry. Those images, in turn, are supposed to have been heavily influenced by Italian painting of the Trecento. In particular a panel painting by Pietro Lorenzetti and a *Crucifixion* by Roberto d'Oderisio are mentioned in this chain of influences.[2] Prominent art historians have also referred in this respect to Altichiero da Zevio's 1384 *Crucifixion* on the altar wall of the Oratorio di San Giorgio in Padua.[3]

Recently, a peculiar metalpoint drawing has shown up that may shed more light on the process of transmission of motifs and ideas in Jan van Eyck's environment, and on the genesis of his *Crucifixion* painting in particular.[4] As the genesis of paintings is, by nature, a technical process, this drawing has also been the subject of technical investigation. The drawing, measuring 254 × 187 mm, has a brownish-yellow tone that slightly obscures the subject: a large crowd of bystanders around a crucifixion (Figure 2).[5] This drawing shows an obvious relationship to Van Eyck's New York *Crucifixion*.

Figure 1 Jan van Eyck, *Crucifixion*, left wing of a diptych, c. 1430, oil on panel, 56.5 × 19.7 cm, The Metropolitan Museum of Art, New York.

Figure 2 Jan van Eyck, *Crucifixion*, metalpoint drawing on prepared paper, 254 × 187 mm, private collection.

The *Crucifixion*

The New York *Crucifixion* is painted with a strong attention to narrative aspects of the events that took place at the crucifixion of Christ.[6] It depicts the moment when Longinus stabs his lance in Christ's side to confirm his death. At the foot of the three crosses is a large gathering of people on foot and horsemen, gawking, cheering and arguing. In the foreground, dressed in purple, is the Virgin Mary weeping in despair, surrounded by her two sisters Mary Cleophas and Mary Salome, and John the Baptist. Behind the three crosses is a fantastic landscape with the city of Jerusalem and hazy light blue mountains further in the background. All details – from the bare cragged rocks with people in the foreground to the infinite vista of the hazy mountain range in the background – are rendered with astonishing sense of depth and great subtlety of definition. This description for the painting holds equally well for the drawing. There are, however, remarkable similarities and differences between the painting and the drawing in the way this scene is depicted. In the drawing as well as in the painting we find 'the infinitely small combined with the astonishingly lifelike'. In both works, the artist similarly demonstrates his ability to attend to the detail, without losing command over the general arrangement. Both works show, in spite of all the details, the same measure of coherence and organisation. In the foreground is Christ's mother supported by St John. The physiognomy and expression of the faces of both Mary

Figure 3 (a) The Erythraean Sybil in the New York painting and (b) in the metalpoint drawing.

and John on the painting and drawing are strikingly similar to the faces on other paintings of crucifixions, sometimes attributed to Van Eyck: one in Berlin and the other in the Ca'd'Oro in Venice. In the drawing as well as in the New York painting, both are accompanied by a group of weeping women. These figures are clearly placed together as a group and separated from the rest of image. Just aside from this group in both works (in the painting to the right of the group of weeping women, in the drawing more to the foreground to the left of the group) is a dramatic loose-haired Magdalene, gazing at the crucified Christ. In doing this, she draws our attention from one focal point of the picture, the group around Mary with the weeping women on the foreground, to the other focal point: the crucified Christ. Thus, in spite of its peculiar vertical, narrow stretched format, the painting retains its sense of space and organisation.[7]

In the painting, there are two figures that do not seem to participate in the dramatic action in either of the points of attention. To the left is a figure seen from the back who seems to point and refer to the Crucified and to the right is the Erythraean or Cumaean Sybil, both of whom represent a theological argument.[8] They do not participate in the action; they do not interact with the other figures. They are, however, very significant. And also the way they are represented is often considered iconographically significant. Their presence has sometimes been explained as the one facing towards Christ, and the other turning away from him. On the painting, the Erythraean Sybil is directed towards the group around Mary and St John. On the drawing, however, the very same Sybil is – still not interacting with any of the people present – turned towards the crucified Christ (Figure 3). A striking element in both images is the figure of Longinus, the Roman soldier who pierced Jesus in his side with a lance. According to the *Legenda Aurea*, Longinus was blind and needed his hand guided by an assistant to accomplish the act. The spilling of Christ's blood cured his eyes, and made him see the light. This iconographic motif, the depiction of the piercing of Christ's side by two persons, shown in both works in a similar manner, is rather uncommon.[9] In both cases, i.e. in the drawing as well as on the painting, the actors have their own individual character. Both works of art testify to Van Eyck's acuity of vision, placing the narrative of the crucifixion into the viewer's immediate realm of experience.

There are other, also quite interesting differences. These differences primarily relate to the way groups of people are organised; they are about the manner in which the grouping of people and the relations between them is controlled: stage direction. In the drawing, the emphasis is on the interaction between the individual figures. This interaction holds the different groups of people together, and determines the organisation of the composition. The gesture of Mary Magdalene bridges the distance between the figures on the foreground and the crucified Christ. In the painting, the group of women is separated from the horses and riders around the cross by an open ground, which is traversed by two people. In using this prop, the painter emphasised the distance between the two groups. It almost seems as if it was for this reason that the Erythraean Sybil could be turned towards the Marys. With the Magdalene and the two persons crossing the open ground, the distance between the two groups is effectively bridged. Adding another connection would have been redundant.

Drawing and underdrawing

The characteristics of the present metalpoint drawing agree well with those of underdrawings of accepted Eyckian paintings. The underdrawing for the draperies of the *Three Marys at the Sepulchre* in Rotterdam, for instance, shows a type of hatching that is quite similar to the hatching of comparable passages in the metalpoint drawing. It consists of a very fine dense hatching, running at an acute angle, almost parallel to the main contours. Outside of the figure, the shape of the drapery is set off against the background by hatchings placed at straighter angles to the figure.[10] The manner in which dark-and-light contrasts and definition of contours are handled are generally considered to be characteristic for the working practices of Jan van Eyck. Similar hatching can also be found in and around the figures of the Erythraean Sybil and the Mary Magdalene on the drawing. The same network with hatching of curved vertical strokes also occurs in the miniatures of hand G (now accepted as by Van Eyck) in the *Milan-Turin Hours*.[11] Butler and Van Asperen de Boer have published reflectograms of the underdrawing of Christ in Gethsemane in the *Milan-Turin Hours*, in which some of the hatchings are strikingly

Figure 4 (a) Detail of horsemen in the drawing; (b) detail of horsemen in infrared reflectogram (IRR) from the New York panel (Dr Maryan Ainsworth).

similar to those on the present drawing. In particular, the crisp underdrawing for the two rocks at the left on the miniature is identical to the manner in which the rocks on the lower left of the drawing is executed. Also the way in which the folds of the draperies fall and the complex hatching to set the figures of the sleeping apostles off against the rocks finds its equivalence in the metalpoint drawing.[12] Similar features could also be found in the underdrawing for Jan van Eyck's *Saint Francis of Assisi Receiving the Stigmata* in Turin. Many of the hatchings in St Francis' habit are drawn parallel, or just slightly oblique to the main contours, very much in the same way as for the Erythraean Sybil in the metalpoint drawing. The shape of Brother Leo on the Turin painting is set off against the rock with dense hatching that is remarkably similar to the manner in which the horses and the group of women around Mary are set off against the background in the metalpoint drawing.[13]

But most importantly, the characteristics of the drawing hold up quite well in comparison with the reflectograms of the New York painting, which were made in the 1980s. The underdrawing of the painting is done in a liquid medium with a very fine brush. In spite of the differences in medium, i.e. metalpoint on paper versus brush and ink on panel, the drawings appear quite comparable. In both drawings we find a similar modelling of forms with parallel hatching indicating the shadows in forms and draperies. In both drawings the contour lines are long and powerful, and filled with shorter modelling strokes. The description by Stephanie Buck characterises both drawings equally well: 'The foreground figures are similarly outlined with continuous strokes; narrow parallel hatchings and cross hatchings are placed rectangularly around these contours to bring the figures into relief and to indicate shadow. Long strokes with a thicker, roundish end which clearly divide the folds, and fine parallel hatchings that follow the direction of the ridge, characterize the modelling of elaborate draperies.'[14]

New reflectograms of the New York painting were made in 2012 by Maryan Ainsworth of the Metropolitan Museum of Art. These reflectograms, recently presented at the Van Eyck Studies Colloquium in Brussels, are of much higher resolution and allow for an even better comparison of the underdrawing of the New York painting with the metalpoint drawing.[15] The similarity is most telling in the hatching of the bodies of the horses. In both cases, the same type of hatchings do not only show these horses in an emphatically three-dimensional way – the subtle play of light and shadow also beautifully suggest the working of powerful muscles under smooth skin. The changes of movement and planes that can be observed in the angular pleats and folds of the gambesons of the two riders (the rider in the centre of the drawing at the foot of the cross; in the painting on the rider at the left) are done in an identical dense network of subtle strokes supported by heavier but soft contours.

The interaction and gestures between the bystanders is similarly drawn with identical efficient strokes with a brush or stylus for the outlines, followed by very subtle hatchings to give volume to the forms and set them off against their backgrounds (Figure 4).

The quality of draughtsmanship in the metalpoint is so high and the placement of contours and hatching is so similar to that on the New York painting, that it is difficult to believe that the metalpoint could be a product of any hand other than the one that made the underdrawing of the New York diptych. The use of metalpoint drawing in relation to underdrawing or preparative drawing is not uncommon in Eyckian painting. The metalpoint drawing of Cardinal Albergati, including its extensively written colour notations, clearly demonstrates that Van Eyck meticulously worked out his design to the smallest detail before actual painting began. Not only Van Eyck's preparative drawing on paper, but also his underdrawing on the panel itself, appears to have been executed in similar detail. Thus, the manner in which pleats of draperies, shadows and volumes in horses and riders, volumes of figures, especially in the group of women and St John in the foreground of the drawing, have been executed is quite comparable with the draperies and the tiny figures on the St Barbara in Antwerp.[16]

All the evidence we have indicates that the present metalpoint drawing is Eyckian, and that it precedes the painting, rather than follows it. The observed differences strongly suggest that the drawing served in the preparation for the *Crucifixion* in New York. The drawing has such refined and meticulously rendered details exceeding the needs for most common preparatory drawings, that the function of the drawing as a *vidimus* cannot be excluded. The use of the drawing as a *vidimus*, however, would not exclude the possibility that it could also have been used as a tool in the actual making of a painting.

The close relationship between the painting and the drawing provokes questions about the possible original function(s) that the drawing may have had. Drawings would work as tools in the studio, as instrumental for the production of paintings, but could also serve as educational tools, as a means of instruction.

The Van Eyck workshop

Drawings as models and patterns for painting were the tools of the trade.[17] A good example of the significance of such drawings is a copy in metalpoint on paper, made after a (now lost) altarpiece by Rogier van der Weyden. At the time, this copy was lent to a colleague, who reproduced it exactly on his own paper. The result is a fifteenth-century drawing, now in the Kupferstich-Kabinett in Dresden, which is identical to a drawing in the Louvre in Paris.[18] Geographically widely dispersed studios could produce, precisely or roughly, similar paintings based on the same example. Journeymen gathered drawings in modelbooks. They travelled abroad, picked up new ideas and established formulae, tried to blend them with their own formulae, and brought them back home: as loose sheets of paper or bound in modelbooks. These foreign examples functioned in the development of new repertoires. Various details – the drapery of a Madonna, the head of a prophet, an angel for an annunciation – were often combined in different arrangements into entirely new compositions.[19] Not much is left of the drawings or of the modelbooks that were used in this type of production.[20]

As well as being an accomplished individual artist, Jan van Eyck was, especially in his later career, also the master of a workshop. The notion of the employment of workshop assistants in Jan van Eyck's studio, in particular around the late 1430s, has now generally been accepted. In his workshop, similar use of drawings would have been made. There is, however, scant knowledge as to how Van Eyck's assistants actually followed his example. We know of some compositional drawings that assistants made after finished paintings by the master. Such drawings were made to design compositions, architectural elements, figure settings and ornaments in new paintings. Stock patterns on paper must also have played a significant role in the operation of Jan van Eyck's studio.[21] A pen drawing in the Albertina in Vienna is generally considered to be a copy of a lost painting by Van Eyck, and a silverpoint drawing in Brunswick closely copies a passage in the Budapest painting.[22] Similarly, the *Madonna of Maelbeke* (itself a copy: Ypres Madonna, oil on panel, 172 × 99 cm, Brugge, Groeningemuseum), is meticulously copied in two drawings: one in the Germanisches Museum in Nuremburg (135 × 150 mm), and one in the Vienna Albertina (278 × 180 mm). A drawing in the Berlin Kupferstichkabinett is a close copy after the Antwerp *Madonna at the Fountain*.[23] In the making of those drawings, the copyists tended to follow the example very closely. Usually there are no, or only very minor, deviations. The original motif is always extremely faithfully followed, and any differences between copy and exemplar were only caused by the presence or absence of individual abilities of the copyist. A fair number of such examples still survive. But, with the exception perhaps of the metalpoint drawing of *Cardinal Albergati*, all Eyckian drawings seem to be later copies, by assistants and followers, of finished works by the master.[24]

The present drawing (Figure 2) does not appear to have the characteristics of the common workshop copy. In this case, the drawing apparently represents an earlier stage in the working process for the New York painting. The relationship between the drawing and the painting seems to reflect a large range of considerations taken into account in order to reach satisfactory solutions. It seems as if some of the original motifs and compositional arrangements in the drawing have been considered, only to be rejected or changed in the painting. Clearly, the drawing was not made in order to be simply, and mechanically, transferred onto the panel, and carefully followed in an underdrawing. The drawing, rather, seems to have functioned in the process that preceded that stage. In contrast to the drawings and paintings by his assistants and followers, the genesis of Jan van Eyck's own autograph works, miniatures as well as paintings, can be characterised as a process of ongoing invention by omission and addition.[25] In the painting, decisions were made that differ from the choices in the drawing – the Sybil turned around, the middle ground opened up (Figure 3). In the painting, the composition

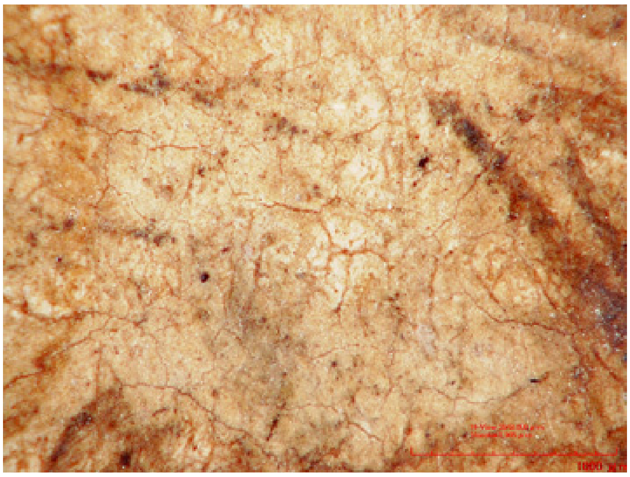

Figure 5 The paper fibres covered by a closed layer of bone white. Micrograph (026) (spot01-007), 50× (800×, scale bar = 100 µm) scale bar = 1000 µm.

in the background is organised in an almost perfect circle around the central cross. The two other crosses stand behind that group. In the drawing, all three crosses are surrounded by a far less organised group of horses and riders, soldiers and bystanders. In the drawing there is no clear distinction between the group with St John and Mary in the foreground and the three crosses further in the background. In the painting, however, the composition is divided emphatically between the group with the women and the densely populated group around the crosses. This requires a measure of independence and self-assuredness that can only be attributed to the master himself. The painter affords himself liberties to the drawing that would never be allowed to an assistant.

These circumstances provoke more technical questions about the relationship between models and final products, and between the drawing and the painting. For an understanding of this relationship it may be rewarding to study the methods and materials used in the making of the drawing.

Methods and materials

The paper measures 25.4 × 18.7 cm, which could not be related to any standard paper size of the time. There is a piece of rather heavy, 'cardboard-like' paper glued to the back of the drawing. This made it impossible to measure any chain lines, laid lines or water marks of the paper. Elemental analyses of the substrate showed it to be covered with a very calcium-rich compound. This compound is also fairly rich in phosphorus. This is entirely consistent with the method described in the historical sources for the preparation of paper for metalpoint drawings.

An extensive description of the process can be found in a manuscript text, written in July 1398, by a certain Johannes Alcherius: *De coloribus diversis*.[26] The text prescribes to calcinate animal bones (or stag horns), to burn off all the remnants of flesh, sinew, other proteinaceous material or fat, and retain only the bare bone material. Then, the calcinated bones were ground to dust, washed, dried and heated again. The resulting pure, burnt white bone dust is then mixed with very dilute gelatinous animal glue. With this watery or milky suspension, various substrates could be given a very thin coating. The recipe states that this preparation could be applied on paper or parchment, but also on panels or canvas. When dry, the surface of the coating could be burnished to a perfect ivory white smoothness. Only when this substrate was perfectly smooth was it ready, so that one could draw on it in black lines with a pencil or metalpoint of gold, silver, bronze or brass: 'quo possis super ipsas protrahere nigro cum grossio, seu stilo auri, argenti, latonis, vel aeris'.

In other recipes, the use of calcite, lead white, sea shell or egg shells are prescribed for ground layers. In our analyses of the preparation layer on the paper, we had sufficient evidence to identify it as calcined bone. In all our energy dispersive X-ray fluorescence (ED-XRF) measurements, we found consistent peaks for calcium and phosphorus, the elements that make up the calcium phosphate of bones.[27] A tiny particle eased out from between the paper fibres at the outer edge was examined with polarised light microscopy (PLM).[28] The optical characteristics of that particle were in perfect agreement with those of a laboratory-made reconstruction of bone white. This was further confirmed with non-invasive X-ray diffraction analyses (XRD) that could be performed directly on the object. These analyses also identified the substrate as one based on hydroxyapatite, i.e. the basic structure of bone white.[29] This provided the substrate for the metalpoint drawing. Under the microscope, this layer appeared as a relatively smooth layer, effectively covering the paper fibres (Figure 5).

We have learned that Van Eyck and other artists of the Middle Ages used drawing points made from a wide variety of metallic substances: gold, silver, copper, lead, tin, and alloys such as bronze or brass, or lead-tin compositions. The frequent mention of silver in the technical sources suggests that it was the preferred metal.[30] Reconstruction experiments with several metalpoints, in the 1950s and recently (2012) at the Amsterdam conservation studios were quite informative.[31] All the previously mentioned metals tended to produce, on the same prepared surface, similar, even greyish, unbroken lines with little texture. Observation under the microscope at stronger magnification revealed that those lines are characterised by tiny scattered metallic flakes and particles.[32] This was also observed in the present drawing. The lines that were done in silverpoint show up under magnification as black accretions on top of a relatively smooth bone white ground (Figure 5). The shapes and sizes of those particles were not specific enough to distinguish one from the other by particle morphology alone. Those lines, however, could be distinguished directly on the object on the basis of their X-ray fluorescence spectra.[33] It is rarely possible to take any samples from such art objects, and the material to be analysed in these drawings is present in only very small quantities. It is estimated that the total of metal particles that is deposited on the surface of the paper would add up to some tens of µg per cm², which would


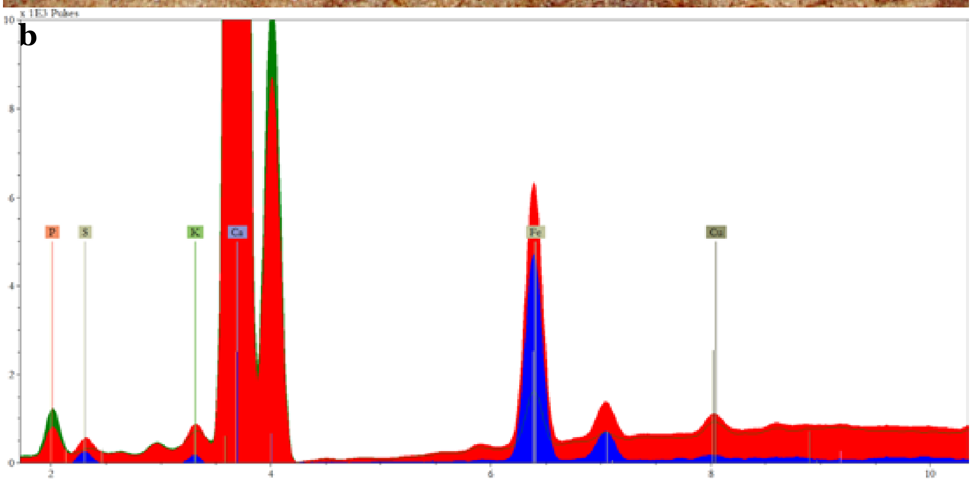

Figure 6 (a) Micrograph of the writing on the paper on the cross; (b) spectrum obtained from dark lines The presence of K and Fe is consistent with iron gall ink. The spectrum (blue) was obtained by the subtraction of elements from the bone white (Ca and P) background.

amount to just some nanometres of thickness of material. Recent developments in open-air μ-XRF instruments now make it possible to perform analyses on such metalpoint lines in the conservation studio. In the past, such analyses could only be performed with highly advanced equipment that required particle accelerators or synchrotron facilities. Duval, Guicharnaud and Dran reported on the use of proton-induced X-ray emission spectroscopy at AGLAE in Paris, for the study of metalpoint drawings.[34] A similar approach was followed by Milota and co-workers in Austria at the Vienna Environmental Research Accelerator (VERA).[35] Reiche and co-workers have extensively published on their study of metalpoint drawings with XRF analyses obtained using synchrotron radiation.[36]

Elemental analyses on the present drawing with a tube-based μ-XRF instrument in the Rijksmuseum's conservation studio turned out to be very informative. These analyses basically confirmed the work of Reiche, Milota, Duval and others. XRF measurements indicated that some areas were not exclusively done in metalpoint, but also in ink. The writing of the INRI sign on the cross, for instance, yielded signals suggesting that it was done in iron gall ink. Iron gall inks were made as the product of the reaction between gallic acids from oak galls and iron salts, usually 'Roman vitriol', a mineral iron sulphate. Strong peaks for iron and significant peaks for potassium (K) and sulphur (S) are consistent with such an ink. This was confirmed by observations at various magnifications with the microscope (Figure 6).[37]

But, more significantly, it transpired that most of the drawing was made with at least two different styluses. One type of line was made with a silverpoint. These silverpoint lines are not made with pure silver, but rather an alloy of silver and copper. With the present XRF equipment, measurements can at best be considered semi-quantitative. The extremely thin and uneven character of the lines makes attempts at quantification very difficult. A guesstimate for the silver:copper (Ag:Cu) ratio could be assumed to approximate 75:25, a ratio that is not dissimilar to the composition of one of the styluses used for the Albergati drawing.[38] The lines in silverpoint on the drawing are also marked by a significant amount of mercury (Hg). This element has

Figure 7 (a and b) Micrograph of silverpoint lines near the face of Christ; (c) the spectrum obtained from silverpoint lines. The signals for Ag and Cu are roughly consistent with a 75:25 ratio. Hg is present. The spectrum (blue) was obtained by the subtraction of elements from the bone white (Ca and P) background.

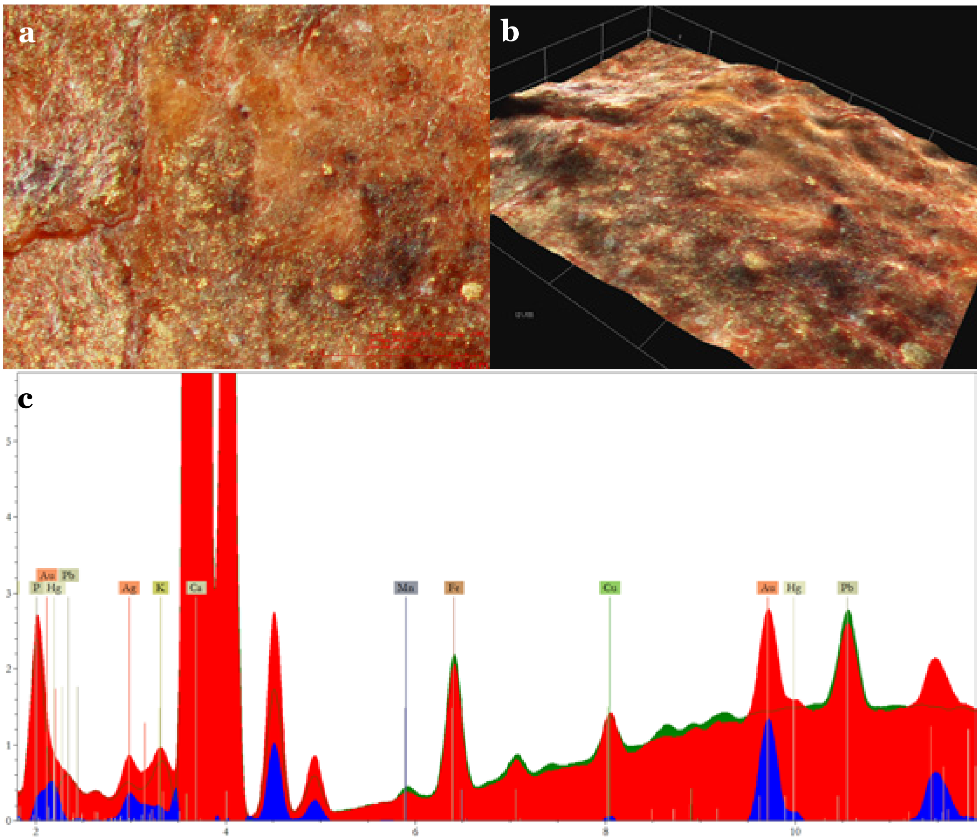

Figure 8 (a) Micrograph of goldpoint lines of the hair of Mary Magdalene (500×); (b) the same goldpoint deposits in topography mode, scale bar = 10 µm; (c) XRF spectrum of gold lines obtained by the subtraction (blue) of elements from the bone white (Ca and P) background (equivalent to 14 carat gold?).

also recently been confirmed in other metalpoint drawings (Figure 7).

The explanation offered by Reiche and co-workers for the presence of Hg as a deposit from atmospheric contamination is not very convincing. Such amounts of deposits would require highly contaminated – and toxically unhealthy – environments. Furthermore, lines executed in goldpoint in the same drawing show no trace of mercury, which certainly would have been the case had the drawing been stored under such conditions. Gold has an even higher affinity to mercury than silver. If the mercury had been deposited from the atmosphere on the silverpoint lines, it would have done so equally well on the goldpoint lines.[39]

It is more likely that the presence of Hg is related to specific mining practices. Silver is hardly ever found as a native metal, but rather tends to be present in grey or sooty black minerals, rocks in which the metal consists of acanthite (silver sulphide), or various complex silver bearing sulphides such as pyargyrite or polybasite (silver antimony sulphides), bromyrite (silver bromide), or proustite (silver arsenic sulphide). Silver also occurs as enrichments of base metal sulphides such as galena, sphalerite and pyrite. If the mined silver ore was rich in lead, it was recovered by a process known as liquefaction. This worked particularly well with high-grade ores. But silver sometimes occurs in poor lodes or veins that run underground. The silver was then recovered by crushing the ore in a stamp mill. Next, the silver was extracted by grinding up the crushed ores further with mercury, salt water and copper sulphate. In the process, the silver amalgamates with the mercury. The metal is then recovered by driving off the mercury with heat and thus separating the amalgam. This method, now known as the patio process, is particularly suitable for the extraction of the rather poor, low quality ores.[40] The presence of both mercury and copper, therefore, seems fully consistent with contemporary medieval mining practices.[41] In the production of the metal, trace contamination of processing metals, such as Cu and Hg, could not be entirely eliminated. Hence, the clear signals for those metals in our spectra.

The parts of the drawing that were done in goldpoint are, of course, characterised by the presence of gold, but also of fairly large amounts of Cu and zinc (Zn), some Ag, and only occasionally just a trace of Hg. Under the microscope, the traces of metallic gold deposited onto the bone white ground, could be observed at higher magnifications (Figure 8). Initially, both metalpoints would have yielded a similar cool grey mark on the abrasive bone white ground. In time, however, the silver lines would prove to be more susceptible to sulphidic corrosion and slightly change in colour, while the inert gold lines would remain unchanged. These changes – the silver more warm purplish-grey and the gold more cool bluish-grey – are too subtle to be distinguished on the present drawing with the unaided eye. Although measurements were carried out on several lines in the drawing, we were unable to draw any conclusions

Figure 9 Infrared reflectogram of the metalpoint drawing. Goldpoint lines appear prominently visible, whereas silverpoint lines are translucent in the infrared (875 – 1700 nm) range under investigation.

about the distributions of gold or silver lines over the whole drawing, or their possible function. The use of either silver or gold does not seem to be reserved for specific figures in the drawing, nor can we deduce that the use of gold represents a specific stage in the making process, for instance that the first lines would be in gold and the drawing then further worked up in silver, or vice versa. Nor do we have solid proof that the choice for both metals would be deliberate, and based on some intentional colour development, which would have evolved after the drawing was exposed to hydrogen sulphide gases in the environment. To gain a better understanding of the build-up of this drawing and the use of different materials over the surface of the paper, elemental imaging was performed with a recently developed macro-XRF scanner.[42] The elemental images showed that both styluses were used over the whole surface of the paper. There are no indications that specific persons or groups of persons were added at a later stage.

At this point, the examination of the drawing in the infrared wavelengths turned out to be quite useful.[43] Metals, and therefore, pure metallic lines of a drawing are not usually transparent to IR radiation – they tend to absorb the IR radiation and therefore often appear as black in the reflectograms. Reconstruction experiments in the conservation studios of the Rijksmuseum showed that this was indeed the case. Initially all metalpoint lines showed up quite nicely. If, however, the metallic silverpoint lines were exposed to H_2S gases, and thus effectively converted into AgS lines, those lines, no longer being metallic, became increasingly translucent to IR radiation.[44]

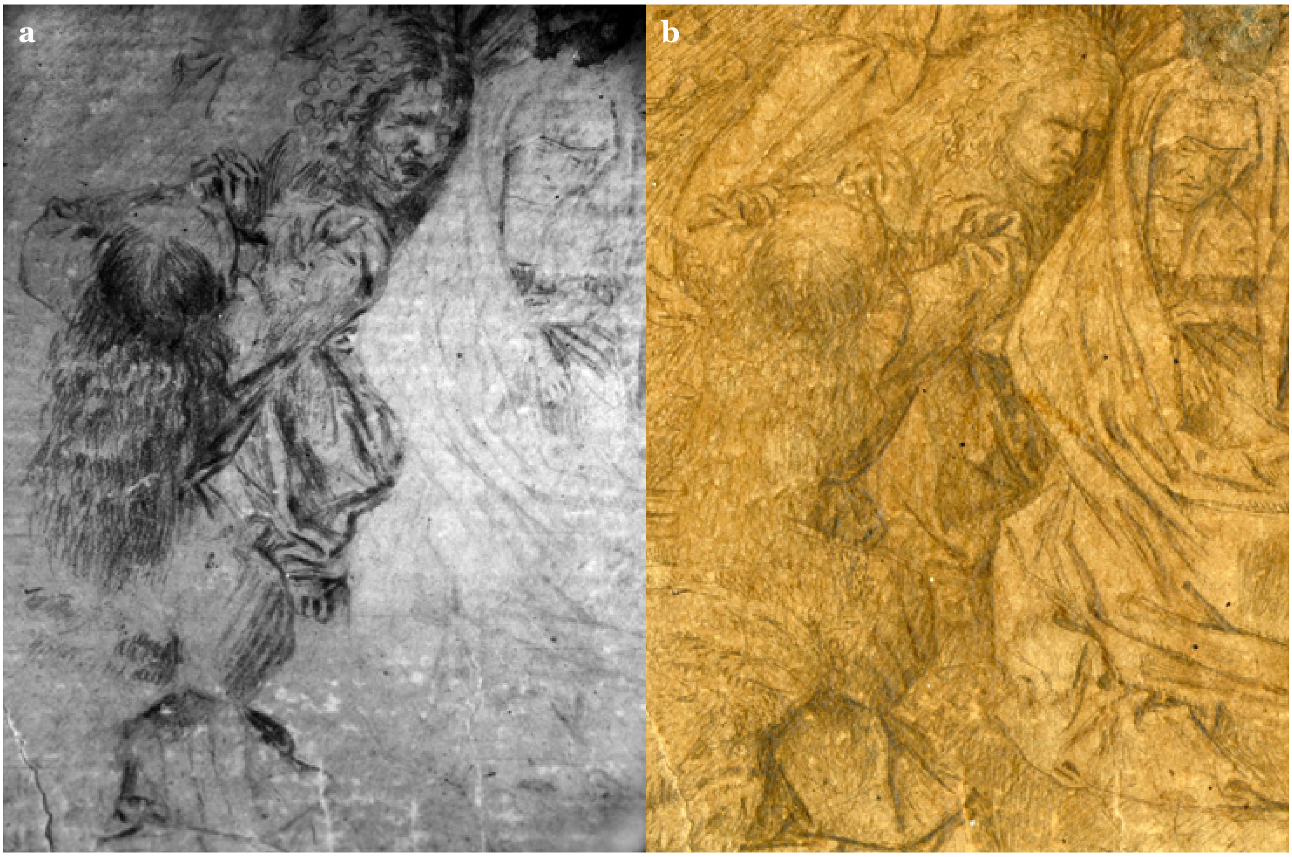

Figure 10 Detail of St John and the figure of Mary Magdalene: (a) infrared reflectogram of the metalpoint drawing, lines in goldpoint; (b) the same detail in normal light.

In the reflectogram of the drawing, the lines in silverpoint, no longer absorbent, were invisible. However, the lines in goldpoint remained quite prominently visible in the reflectogram (Figure 9). In fact, the lines in gold appeared more visible in the infrared reflectogram (IRR) than in normal light. This is particularly prominent in the expression on the face of St John and in the figure of the dramatic Mary Magdalene (Figure 10 a and b).

In the IRR it became clear that the drawing had a stronger emphasis on the dramatic aspects of the event than the painting. The thief on the right has all the signs of suffering. His body originally was more twisted and contorted, and his left leg (drawn in goldpoint) came loose. In the painting, the bodies of the thieves to the left and right of Christ are made to draw much less attention (Figure 11 a–c) This dramatic aspect links the drawing even closer to a *Crucifixion* in a book of hours, now in the Österreichische Nationalbibliothek in Vienna, datable to c. 1420 by the so-called Bedford Master. This may add further support to the suggestion that some of Jan van Eyck's images could have been influenced by workshop patterns from French manuscripts.[45]

There are no other autograph drawings that show such a direct genetic relation between drawing and painting. In the case of the Albergati drawing in Dresden, the drawing primarily seems to have served to produce precise guidelines for the painting. However, the present metalpoint drawing for the New York painting is not a fixed design to be strictly followed in painting, but rather precedes the underdrawing for the panel by several steps in the design process. It cannot be argued with any degree of probability that in doing this, the image, or parts of it, had been literally transferred from the smaller drawing to the larger panel by a fixed proportional ratio.[46]

Yet, it seems that the present drawing was not only used as a tool to develop themes and compositions. It did not only serve as an approximate source of inspiration and ideas. It also appears to have been used as exemplar for direct and literal reproduction. There are contemporary precedents for such direct reproductions. For instance, on the back side of a fifteenth-century drawing in the Kupferstich-Kabinett in Dresden (inv. no. C787, 21.4 × 15.2 cm) a contour in traces of black chalk could be seen. These traces are the remnants of a mechanical reproduction process. In this process the back side of a 'parent' drawing was dusted with black pigment, charcoal powder. The drawing with the powdered side below was then laid over an empty sheet of paper. Next, the contours of the drawing were traced with a pointed peg, a 'blind' stylus, or the pointed back side of a brush. The pressure of the point translated through the paper and resulted in the deposition of the pigment powder onto the target surface, paper or prepared panel. In this manner, the tracing of the 'parent' drawing was – though sometimes slightly vague – transferred onto the new paper. After the 'parent' drawing was taken off, the pigment powder could easily be brushed or even blown off from the back

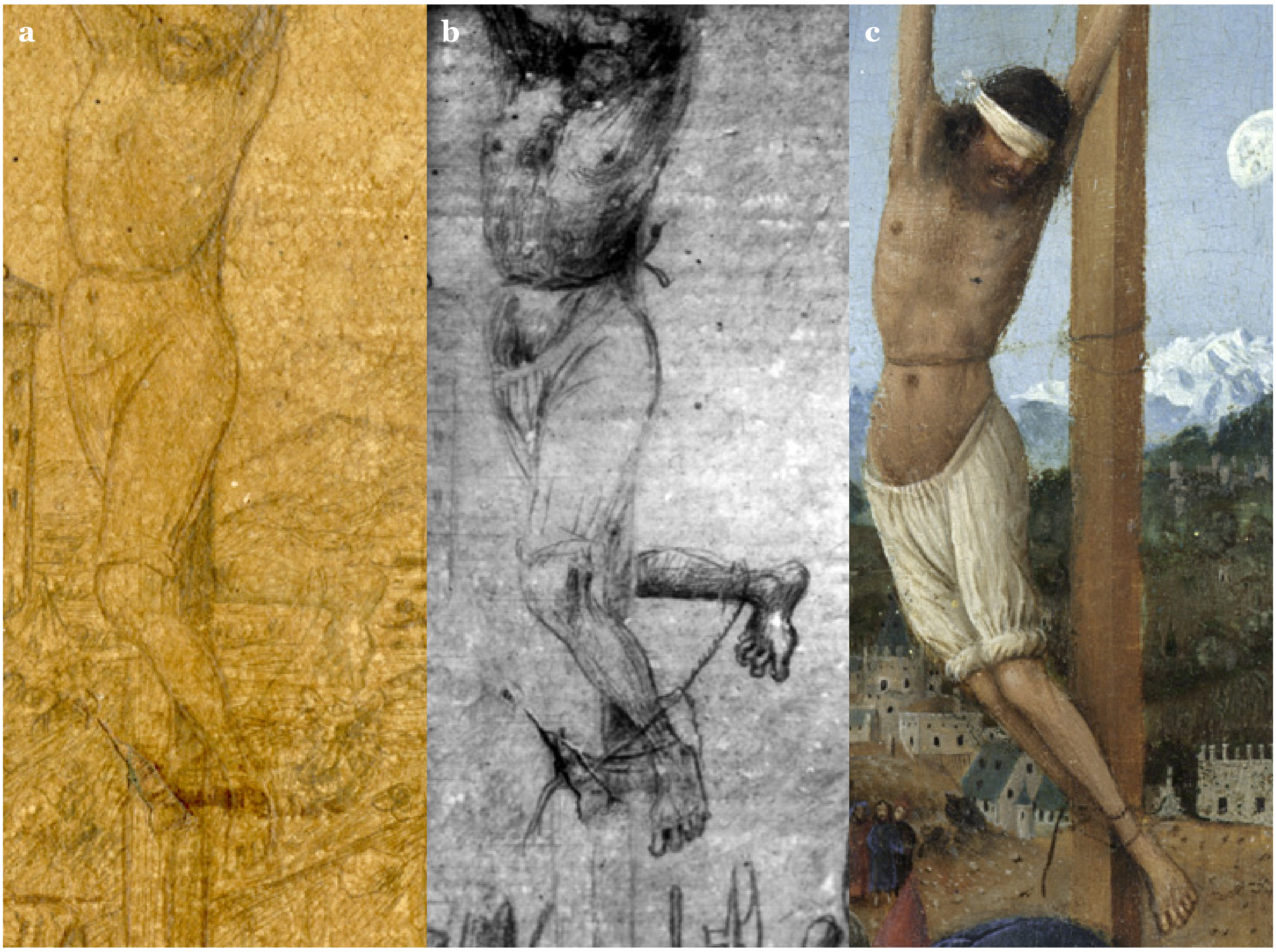

Figure 11 (a) Detail of the crucified figure in the metalpoint drawing in normal light; (b) the same detail in an infrared reflectogram; (c) the equivalent detail from the New York *Crucifixion*.

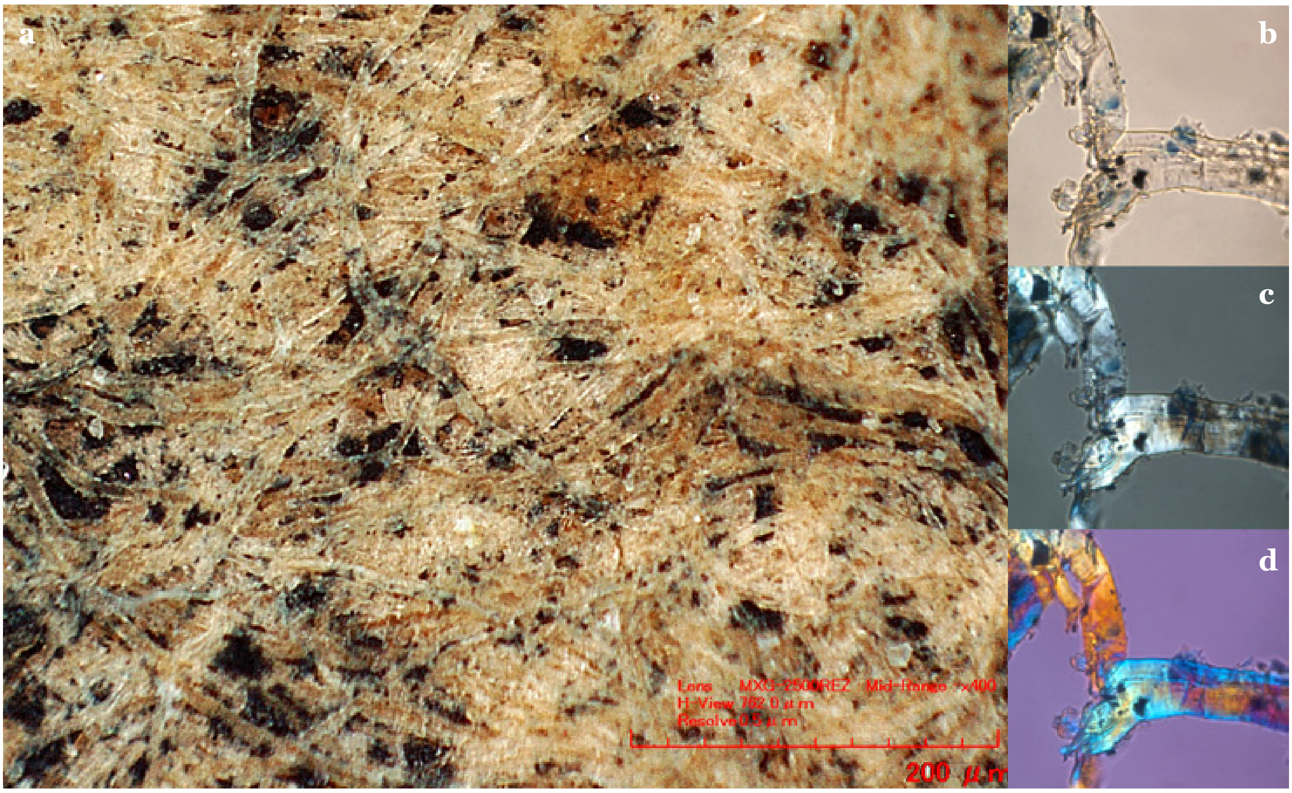

Figure 12 Dark indigo pigment powder on the back side of the metalpoint drawing, adhering to the fibres of the paper: (a) micrograph, 400×, scale bar = 200 µm (b) micrograph in transmitted polarised light; (c) micrograph in transmitted polarised light, crossed polars; (d) micrograph in transmitted polarised light, crossed polars lambda waveplate inserted (500×).

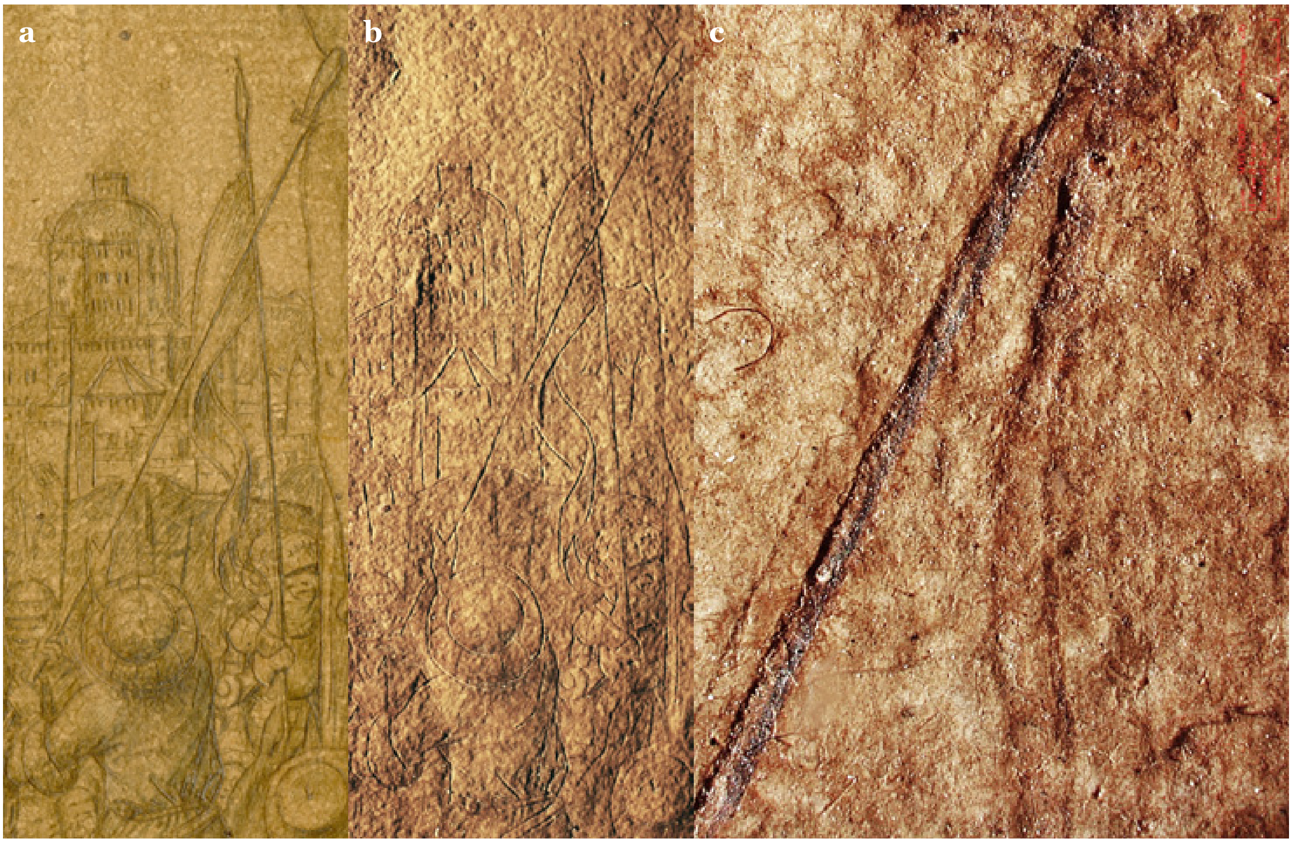

Figure 13 Detail from the metalpoint drawing: (a) in normal light; (b) same detail, photograph of the drawing in raking light; (c) indentation in the paper from the blind stylus, micrograph in raking light, 35×, scale bar = 2 mm.

side of the original paper. Using this technique, the image of the Dresden 'parent' drawing ended up as a painting on panel, which is now attributed to the studio of Bouts (*Mary and the Christ Child*, oil on panel, 31.2 × 22.2 cm, Frankfurt Städelsches Museum, inv. no. 1217).[47] The Dresden 'parent' drawing is executed in a brown and black ink. Traces of black chalk, under this ink, strongly suggest that this drawing may itself have been the result of such a copying act. Because these drawings were heavily used, they were subject to the wear and tear of everyday handling. They were rubbed in with pigments, traced with sharp tools, handled with dirty fingers, folded and bent, over and over again. Because of this abrasion and, of course, changes of fashion in style or subject, only an extremely limited number of them have survived.

The present Eyckian metalpoint drawing shows similar typical features that may be associated with this sort of one-to-one tracing reproduction. On the back side of the drawing, a newer piece of paper has been pasted. Over time, this support became damaged, so that the back side of the original paper shows through. Close examination of the now exposed back side of the paper showed that the paper fibres are covered with a deep blue, almost black, rather granular pigment[48] (Figure 12). Also, on the front side of the drawing, in areas where the paper has suffered from abrasion, some of this dark pigment shows through from the back – this is clearly the sort of pigment deposited onto a target substrate in a mechanical transfer process. Traces of this practice cannot only be seen on the back side of the drawing – when the drawing is observed under raking light, notable indentations in the paper can be seen that were clearly caused by the use of a blind stylus in the tracing process[49] (Figure 13). Close observation of the drawing shows that this (repeated?) tracing has imparted a certain rigidity at the outlines of many figures. This may make them appear rather more heavy-handed than originally intended. Of course, these stiff and heavy contours have to be taken into account in answering questions of attribution.

The brownish tonality that the drawing now has may well be explained by its possible original function in Jan van Eyck's studio as a reproducible image. In order to render a model on fairly translucent paper (which may be useful in the process), it was sometimes treated with oils. The whiteness and opacity of paper is dependent on the difference of its refractive index and that of the surrounding medium: the air. Large differences in refractive indices lead to a strong scattering of light, and the object appears white. Refractive indices for the linen or hemp fibres of which rag paper was usually made are $n\gamma = 1.58$, $n\alpha = 1.52$.[50] In the open air, with a refractive index of just above 1.0, this difference is enough to scatter the light and thus make the paper appear white. The bone white used for the preparation of the paper, having even higher refractive indices, makes it appear even whiter.[51]

Introduction of oils, such as linseed oil or walnut oil, connects and embeds the fibres of the paper in a liquid with an almost similar ($n \approx 1.50$–1.52) refractive index. Then, the light that falls on the paper is no longer scattered, but transmitted through the paper. The paper – if thin enough – appears transparent.[52]

In a reconstruction experiment we used a relatively fine rag paper (consisting of linen fibres with a slight addition of some cotton fibres), which we coated with bone white pigment, bound in a dilute, proteinaceous medium. The reconstruction drawing executed on this prepared coating did indeed become rather translucent after staining with essential and drying oils. This translucency appeared quite helpful in the tracing process as it showed where and to what extent the pigment powder on the reverse had already been transferred to the 'target support'. The transparency of the paper may have been instrumental in the copying process, i.e. the mechanical transfer of the 'parent' image onto a new substrate. Subsequent discoloration must have been a side effect from the copying process. Of course, at the time when this action took place, the paper merely became transparent – it was only after some time that the oil must have oxidised, polymerised, and gradually turned into its present yellowish-brown state. Upon oxidation, the oil will adhere to the paper fibres as groups of long-chained fatty acids. If a system of conjugated double bonds, a polyene, is large enough, it will absorb light in the visible region of the spectrum and appear coloured. Visual light absorption spectrometry indicates that the maximum for the silverpoint would be roughly around 480 nm, which indicates that, in spite of the overall now generally brownish tone, the original tonality of the metalpoint drawing would have had a much cooler bluish tonality.[53]

This indicates that the drawing must also have served as a source for literal reproduction. At this time, however, it has not been possible to find any of the products that resulted from this process. Only related, but certainly not identical, repetitions of the design of the drawing could be found in a *Crucifixion* by Lieven van Lathem in the 1471 Prayerbook of Charles the Bold, and in the 1510–20 *Crucifixion* by Gerard Horenbout.[54] The *Crucifixion* in the famous Grimani Breviary of c. 1520 is also known to derive roughly from the same Eyckian model.[55]

Conclusion

All the evidence we have places the metalpoint drawing very close to Jan van Eyck in its creation. The characteristics of the drawing and the New York painting are markedly similar. The style and linear qualities in the underdrawing of the painting (visible in the infrared reflectograms of Maryan Ainsworth) and those of the metalpoint drawing are identical. Either the same hand applied the brush and stylus on panel and paper, or two artists worked in such close collaboration that they used exactly the same language of strokes, contours and hatchings. If the metalpoint drawing would not be by the hand of the master himself, then it would be by someone trained in his workshop who worked so closely with him that the two hands cannot reasonably be distinguished. There seems to be no alternative. If we accept the underdrawing for the *Crucifixion* in New York as an autograph intervention by Jan van Eyck, then it necessarily follows that we have to accept the metalpoint drawing as by the same hand as well.

Almost all drawings in this group are done by followers and students after Jan van Eyck's paintings.[56] In this case, the development in time is reversed: the drawing precedes the painting. It is conceivable that a student drew a copy of a painting by the master. It is hard to imagine that a master with the accomplishments of Jan van Eyck would produce a painting after a drawing by an assistant.

We also find in both objects the same pictorial intelligence, the same ingenuity of stage design, the subtle variety of emotions ranging from intense grief to blunt curiosity; the same sense of structural organisation, the same sense of detail without losing oversight of the whole composition, the same sense of sharp-edged contour and volume, line and tone. And, even in the drawing with its gold and silver lines, the same refined sense of coloristic values.

Acknowledgements

The author would like to express his gratitude to: Mr. L. Sozzani, Senior Conservator at the Rijksmuseum, who made the raking light photographs, as well as the UV-fluorescence photographs; Dr. H. Neevel of RCE (Rijksdienst voor Cultureel Erfgoed), who helped with the colour measurements of the paper; Dr. L. Megens of RCE who assisted in the diffractometry of the substrate, and Dr. K.J. van den Berg of RCE who expertly carried out gas chromatography-mass spectrometry work on organic residues in the paper. Dr. M. Ainsworth of the Metropolitan Museum of Art, New York, provided the reflectograms of the New York panel. Thanks are due to Dr. Victor Schmidt of Utrecht University, Dr. B van Velsen, Prof. Dr. C. Chavannes-Mazel, and I. Kneepkens of Amsterdam University, Gwen Tauber of the Rijksmuseum Amsterdam, as well as Dr. M. Ainsworth from New York, and Dr. F. Lammertse of Museum Boijmans van Beuningen, Rotterdam for helpful discussions on problems of attribution.

Notes

1. Jan van Eyck, *Diptych with Crucifixion and Last Judgement*, c. 1430, oil on canvas, transferred from panel, each 56.5 × 19.7 cm, The Metropolitan Museum of Art, New York, Fletcher Fund, 1933 (33.92ab). H.B. Wehle and M. Salinger, *A Catalogue of Early Flemish, Dutch, and German Paintings*. New York, The Metropolitan Museum of Art, 1947; H. Belting and D. Eichberger, *Jan van Eyck als Erzähler*. Worms, Werner'sche Verlagsgesellschaft, 1983.
2. Jean Colombe, *Crucifixion*, and Jan de Limbourg, *Death of Christ*, illuminations on parchment on fols 152v and 153r respectively, in the *Très Riche Heures*, Musée Condé, Chantilly. Pietro Lorenzetti, *The Crucifixion*, tempera on panel, 148.5 × 69 cm, inv. no. 10289, Museo Horatio Stibbert, Florence, and Roberto d' Oderisio, *Crucifixion*, tempera on panel, 89 × 59 cm, inv. MI 358, Musée du Louvre, Paris. A.S. Labuda, 'Jan van Eyck, realist and narrator: on the structure and artistic sources of the New York 'Crucifixion', *Artibus et Historiae*, 27, 1993: 9–30.

3. A. Châtelet, 'Un collaborateur de Van Eyck en Italie'. In *Relations Artistiques entre les Pays-Bas et l'Italie à la Renaissance*, Études dédiées à Suzanne Sulzberger, Institut Historique Belge de Rome, Tome IV, 1980: 43–60. In that crucifixion, the composition was much more compressed than in his earlier (1379) crucifixion for the San Antonio in Padua. J. Richards, *Altichiero: An Artist and his Patrons in the Italian Trecento*. Cambridge, Cambridge University Press, 2000: 230.
4. G. Menssling, Collaborator of Jan van Eyck, *Crucifixion of Christ*, c. 1440. In S. Kemperdick and F. Lammertse (eds), *The Road to Van Eyck*, exh. cat., 2012, forthcoming.
5. The paper for this drawing was most probably of French or Italian origin. In the Netherlands, the first paper mill with documented production was established only in 1586. There was, however, a paper mill already in operation in Gennep in the Lower Rhine region in 1428. As the paper of the drawing is covered on the back side with a thick sheet of 'backing board' paper, and the front side is prepared with a coating to receive the metalpoint tracing, it was not possible to establish chain lines, laid lines and/or watermarks. Nor can any conclusive arguments be drawn from the dimensions of the paper: 25.4 × 18.7 cm. The medieval names of paper formats, established in Bologna, have largely been retained in other European countries. However, under similar names a large variety of dimensions was used in different countries. At this time, the present paper seems to approximate best the dimensions of fractions of the Bolognese Imperiale (50 × 74 cm). P.F. Tschudin, *Grundzüge der Papiergeschichte*. Stuttgart, Anton Hiersemann, 2002: 100–107, 180.
6. Belting and Eichberger 1983: n. 1; M.W. Ainsworth, 'Religious painting from about 1420 to 1500: In the Eye of the Beholder', cat. no. 1'. In M.W. Ainsworth and K. Christiansen (eds), *From Van Eyck to Bruegel,* Early Netherlandish Painting in The Metropolitan Museum of Art. New York, The Metropolitan Museum of Art, 1998: 86–9.
7. The Magdalenes on the drawing and on the panel seem heavily indebted to the Magdalene at the foot of the cross in the *Deposition* of the *Très Riche Heures*, fol. 156v. A similar Magdalene can also be traced down to the so-called 'Orsini polyptych' by Simone Martini in the Antwerp Museum (inv. nos. 257–60), A. Martindale, *Simone Martini*. Oxford, Phaidon, 1988: 171–3, fig. 120, cat. no. 2, iii.
8. The similarity in clothing with a corresponding figure on the outer wing of the Ghent altarpiece gives a strong argument for the identification of this figure as the Erythrean Sybil.
9. Longinus' horse in the New York painting is fairly similar to the first horse on the panel of the *Just Judges* of the Ghent polyptych.
10. J.R.J. van Asperen de Boer and J. Giltaij, 'Een nader onderzoek van de 'Drie Maria's aan het H. Graf' – een schilderij uit de "Groep Van Eyck" in Rotterdam', *Oud Holland*, 101, 1987: 254–76, 259–62.
11. A.H. van Buren, 'Problems and possibilities of the reflectography of manuscripts: the case of the *Turin-Milan Hours*'. In R. Veroughstraete and R. Van Schoute (eds), *Le dessin sous-jacent et la technologie dans la peinture, Colloque XI*. Louvain-la-Neuve, Université catholique de Louvain, 1997: 19–28, 25.
12. Turin, Museo Civico, fol. 30v., M.H. Butler and J.R.J. van Asperen de Boer, 'The examination of the Milan-Turin Hours with infrared reflectography: a preliminary report'. In R. Veroughstraete and R. Van Schoute (eds), *Le dessin sous-jacent et la technologie dans la peinture, Colloque VII* Louvain-la-Neuve, Université catholique de Louvain,1989: 71–6, 74–13. For a comparison of the drawing with the underdrawing of Eyckian landscape background see also: J.R.J. van Asperen de Boer and M. Faries, 'La *Vierge au Chancelier Rolin* de Van Eyck: examen au moyen de la réflectography à l' infrarouge', *Revue du Louvre et des Musées de France*, 1, 1990: 37–49.
13. Jan van Eyck, *Saint Francis of Assisi Receiving the Stigmata*, oil on panel 29.2 × 33.4 cm, Turin Galleria Sabauda; see J.R.J. van Asperen de Boer, 'Some technical observations on the Turin and Philadelphia versions of 'Saint Francis Receiving the Stigmata'. In *Jan van Eyck: Two Paintings of Saint Francis Receiving the Stigmata*. Philadelphia, Philadelphia Museum of Art, 1997: 51–63, 54–5.
14. S. Buck, 'Petrus Christus's Berlin wings and the Metropolitan Museum's Eyckian diptych'. In M.W. Ainsworth (ed.), *Petrus Christus in Renaissance Bruges: An Interdisciplinary Approach*. New York and Brepols, Turnhout, 1995: 65–83.
15. Ainsworth used an Indigo Systems Merlin Near Infrared (NIR) InGaAs camera, with an array format of 320 × 256 pixels. The camera was provided with a custom-made (StingRay Optics) macro lens, optimised for wavelengths from 900 to 2500 nm. It was used in conjunction with a National Instruments IMAQ PCI-1422 frame grabber card and IRvista 2.51 software. The images were acquired as 16-bit .BIN files, exported as 8-bit .TIFF files, and assembled in Adobe CS3 Photoshop. M.W. Ainsworth, 'Jan van Eyck and workshop: The Crucifixion and Last Judgement'. In *Van Eyck Studies*: *Postprints of the Symposium XVIII for the Study of Underdrawing and Technology in Painting*, 2013 (forthcoming).
16. Dated 1437; oil, iron gall(?) ink and metalpoint incision on panel 31 × 18 cm, KMSKA inv. no. 410, J.R.J. van Asperen de Boer, 'Over de techniek van Jan van Eycks De Heilige Barbara', *Jaarboek van het Koninklijk Museum van Schone Kunsten Antwerpen*, 1992: 9–18; R. Billinge, H. Veroughstraete and R. Van Schoute, 'The Saint Barbara'. In S. Foister, S. Jones and D. Cool (eds), *Investigating Jan van Eyck*. Brepols, Turnhout, 2000: 41–8. Recent examinations (by Matthias Ahlfeld and Dr Geert van der Snickt of Antwerp University), of the Saint Barbara with scanning XRF failed to show any evidence for the use of silverpoint underdrawing. Those examinations, however, were performed with a collimated X-ray source rather than by a focused beam in which all the available energy is employed by capillary optics. The scanning experiment was done with the use of a Rhodium anode, rather than the (for detection of Ag) more favourable Mo anode (Dr G van der Snickt, Antwerp University, pers. comm., 9/3/2012). Furthermore, the dwell time in the Antwerp XRF scanning experiment was, by necessity, very short. Other measurements (by Reiche and others) have shown that a rather long duration is necessary for a reliable detection of such nanometer-thin Ag lines. In short: absence of evidence does not necessarily mean evidence of absence.
17. These tools were very valuable – so valuable, in fact, that a conflict over some of such drawings and some pigments could even lead to manslaughter: A. de Champeaux and P. Gauchery, *Les travaux d'art exécutés pour Jean de France, duc de Berry avec une étude biographique sur les artistes employés par le prince [1340–1416]*. Paris, 1894: 205.
18. Inv. no. C779 (20.9 × 18.5 cm), and deptartemente des arts graphiques, inv. no. R.F. 29.069 (22.0 × 18.8 cm), respectively.
19. T. Ketelsen, 'Die Funktion der Zeichnung: Musterbuch, Studie, Kopie, Paraphrase, Vorzeichnung'. In T. Ketelsen, U. Neidhardt, K. Krüger and C. Metzer (eds), *Das Geheimnis des Jan van Eyck*, Die frühen niederländische Zeichnungen und Gemälden in Dresden. Dresden, Deutscher Kunstverlag, 2005: 127, 144.

20. The most authoritative source on the dissemination of motives through modelbooks is: R.W. Scheller and M. Hoyle, *Exemplum*: *Model-Book Drawings and the Practice of Artistic Transmission in the Middle Ages (ca. 900–ca. 1450).* Amsterdam, Amsterdam University Press, 1995.
21. S. Jones, 'The use of patterns by Jan van Eyck's assistants and followers'. In S. Foister, S. Jones and D. Cool (eds), *Investigating Jan van Eyck*. Brepols, Turnhout, 2000: 197–207.
22. Brunswick, Herzog Anton Ulrich-Museum, *Riders from a Crucifixion*, silverpoint on paper, 135 × 115 mm, cat. no. Z 216; and Vienna Albertina, *Christ on the Road to Calvary*, pen on paper, c. 1450, cat. no. Ndl. 22 (Winkler 1958: 83).
23. W.H.J. Weale, *Hubert and John van Eyck: Their Life and Work*. London, John Lane, The Bodley Head, 1908: 92 as Friedrich Wilhem Museum Berlin inv. no. 7120 (1878).
24. Jan van Eyck, *Portrait of Cardinal Nicolo Albergati*, metalpoint on prepared paper, 214 × 181 mm, Kupferstichkabinett Dresden, inv. no. C 775. S. Buck, 'An approach to looking at Eyckian drawings'. In Foister et al. 2000: 183–95.
25. Van Buren 1997: 27.
26. The Alcherius text is included in the collection made up in 1431 by Jehan Le Begue, a lawyer at the Mint in Paris (Paris, Bibliotheque Nationale, MS 6741). M.P. Merrifield, *Original Treatises on the Arts of Painting*. London, J. Murray, 1849: 274–9.
27. Also peaks for Fe and Cu, and traces of K and Mn were found in varying, but minor quantities. Elemental analyses were done with an ARTAX µ-XRF spectrometer, 50 kV, 600 µA, Mo-anode, using a 0.060 µm capillary lens. Measurements usually took 120 seconds. To increase detection of low Z elements a He-flush (1.7L/m) was applied.
28. Bone white was made in the museum's laboratory by charring animal bones in an oxidising atmosphere for 24 hours at 650°C. In both cases, i.e. of samples from the reconstruction and the original object, the translucent, colourless particles showed refractive indices that were just slightly lower than that of our mounting medium (n = 1.662). They had a low birefringence under crossed polars, and rotation of the stage resulted in an obvious undulose extinction. PLM was done in plain transmitted and polarised light, with a Zeiss Standard 17 microscope (200×).
29. This was confirmed with X-ray diffraction (XRD). Direct measurements on the objects were made with a Siemens D8, GADDS (general area detection diffraction system) instrument with CuKα radiation and with monocapillary optics (2 Theta from 18.00° to 56.50° with 100s. steptime). Spacings matching at d= 2.8146, 2.7203, 2.7783, and 3.4400 gave unambiguous identification of hydroxylapatite: $Ca_5(PO_4)_3$3(OH). M.E. Fleet, X. Liu and P.L. King, 'Accommodation of the carbonate ion in apatite: an FTIR and X-ray structure study of crystals synthesized at 2-4 GPa', *American Mineralogist*, 89, 2004: 1422–32. Most other XRD analyses were done with 57.3 mm Gandolfi cameras with CuKα radiation, voltage set at 40 kV, with current at 30 mA, exposure times varied from 1:30 to 5:30 hours. See also: M.I. Kay, R.A. Young and A.S. Posner, 'Crystal structure of hydroxyapatite', *Nature*, 204, 1964:1050–52, and R.M. Wilson, J.C. Elliott, S.E. Dowker and R.E. Smith, ' Rietveld structure refinement of precipitated carbonate apatite using neutron diffraction data', *Biomaterials*, 25 (11), 2004: 2205–13.
30. J. Bescoby, J. Rayner and S. Tanimoto, 'Dry drawing media'. In J. Ambers, C. Higgitt and D. Saunders (eds), *Italian Renaissance Drawings: Technical Examination and Analysis*. London, Archetype Publications, 2010: 39–56.
31. J. Watrous, *The Craft of Old Master Drawings*. Madison, WI, University of Wisconsin Press, 1957: 12–23. With the help of the paper conservator and lecturer of Amsterdam University, Dr Bas van Velsen, we obtained a pure linen fibre paper, coated it with a bone white ground layer (see note 18) and made marks on it with tin, lead, lead-tin alloy, copper, brass, zinc, bronze, platinum, silver and gold metalpoints. Analytical measurements and microscopical observations made of these reconstructed lines were continuously compared with those from the actual object. Again, in our XRF measurements, a He-flush (1.7 L/m) was applied, to improve the assessment of low Z elements. This was also instrumental in removing disturbing signals from argon in the air (Kα = 2.957 keV, Kβ = 3.191 keV) that would affect the measurement of Ag (Lα = 2.984 keV, Lβ = 3.151 keV) lines.
32. Light microscopy performed with a HIROX KH-7700 digital microscope with 2.11 megapixel CCD sensor, res. max. 10.000 × 10.000 pixel, magnifications 35–2000×.
33. Elemental analyses of the metalpoint traces were also done with the ARTAX µ-XRF spectrometer, 50 kV, 600 µA, Mo-anode, using a 0.060 µm capillary lens. Most measurements took only 120 seconds. However, to assess the validity of our measurements on these nanometer-thin metal strokes, some dwell times were expanded to as much as 600 seconds.
34. A. Duval, H. Guicharnaud and J.C. Dran, 'Particle induced X-ray emission: a valuable tool for the analysis of metal point', *Nuclear Instruments and Methods in Physics Research*, B 266, 2004: 60–74.
35. P. Milota, I. Reiche, A. Duval, O. Forstner, H. Guicharnaud, W. Kutschera, S. Merchel, A. Priller, M. Schreiner, P. Steier, E. Thobois, A. Wallner, B. Wünschek and R. Golser, 'PIXE measurements of Renaissance silverpoint drawings at VERA', *Nuclear Instruments and Methods in Physics Research*, B 266, 2008: 2279–85.
36. I. Reiche, A. Berger, W. Görner, S. Merchel, M. Radtke, J. Riederer, H. Riesemeier and M. Roth, ' Following the traces of Albrecht Dürer: analysis of silverpoint drawings by spatially resolved synchrotron-induced X-ray fluorescence analysis', *Nuclear Instruments and Methods in Physics Research*, B 266, 2004: 83–91; I. Reiche, M. Radtke, A. Berger, W. Gorner, T. Ketelsen, S. Merchel, J. Riedrer, H. Riesemeier and M. Roth, 'Spatially resolved synchrotron-induced X-ray fluorescence analyses of metalpoint drawings and their mysterious inscriptions', *Spectrochimica Acta*, Part B, 59, 2001: 1657–62. See also I. Reiche, S. Merchel and M. Radtke, 'Auf den Spuren Albrecht Dürers – Zerstörungsfreie Spurenanalyse mit ortsaufgelöster Synchrotronstrahlungs-induzierter Röntgenfluoreszenzanalyse', *ZfP-Zeitung*, 96, 2005: 40–45.
37. The use of iron gall inks on the drawing was also suggested by so-called 'false colour infrared' imaging. See: J. Havermans, H. Abdul Aziz and H. Scholten, 'Non destructive detection of iron-gall inks by means of multispectral imaging', *Restaurator*, 24, 2003: 88–94.
38. XRF measurements were made with the use of Bruker quantitative software, with the use of the fundamental parameters software, and with PyMCA. Certified standards for comparison were obtained from WaarborgHolland, Europe's Assay Office. These standards were applied to a pure bone white/parchment glue preparation layer. Measurements of standards and samples were taken during 600 seconds (see note 33). Even under these circumstances, the results should be interpreted with caution. Such a similarity cannot be taken as solid proof that a same stylus would have been used by the same hand. Reiche et al. 2001: 1661.

39. I. Reiche, S. Merchel, T. Ketelsen and O. Simon, 'Alc ixh xan; Zum zeichnerischen Kalkül Jan van Eycks'. In Ketelsen et al. 2005: 8–13, 9. Reiche et al. 2005: 44.
40. Bartolome de Medina is often credited for the invention of this process, but this credit seems to be based primarily on the patent that he obtained from the Viceroy of South America. Bartolome did not really invent the process. He had learned the principle from a German master, Leonard, and merely applied it on industrial scale in the Spanish provinces in South America. A. Probest, 'Bartolome de Medina: the patio process and the sixteenth century silver crisis'. In P. Bakewell (ed.), *Mines of Silver and Gold in the Americas*. Brookfield, VA, Variorum, 1997: 96–112.
41. V. Biringuccio, *The Pirotechnia of Vannoccio Biringuccio: The Classic Sixteenth-century Treatise on Metals and Metallurgy*, C.S. Smith and M.T. Gnudi (trans. and eds). New York, Dover Publications, 1990: 47, 142, 384. L.D. de Lacerda and W. Salomons, *Mercury from Gold and Silvermining*. Berlin and New York, Springer-Verlag, 1998.
42. The instrument was a Bruker M6 Jetstream scanning instrument. The surface of the entire drawing was scanned in three cycles, with the excitation radiation of 35 kV and 500 µA from a Rh anode focused onto the 356 µm measuring spots with a monocapillary lens. Step size was 350 µm with mechanical res. 267. Dwell time was 50 msec. Elemental distribution maps were created for Ag, Pb, Fe, K, Au and Ag.
43. Infrared reflectography (IRR) was done with an Osiris 512 × 512 infrared camera, equipped with a Hamamatsu (G11135-512DE), InGaAs image sensor allowing a 4096 × 4096 pixel capture area. The sensitivity in the NIR region extended to approx. 1700 nm. Visible light was filtered off at 875 nm by a Schott RG830 filter.
44. S. Tanimoto and G. Verri, 'A note on the examination of silverpoint drawings by near-infrared reflectography', *Studies in Conservation*, 54, 2009: 106–16.
45. Buck 1995: 70–72, fig. 5.
46. In the (re)production of paintings after the examples of Rogier van der Weyden, often the same geometrical relationship was followed in the mechanical copying process, with reduction factors approaching 0.577 and 0.866. J. Dijkstra, *Origineel en Kopie: Een onderzoek naar de navolging van de Meester van Flemalle en Rogier van der Weyden*, PhD thesis, University of Amsterdam, 1990: 102–04, 190–92. Jan van Eyck appears to have used a geometric ratio of about 40%, almost identical to an enlargement according to the square root of 2 (= 1.41). The advantage of such a system is in its scaling: if a rectangle with an aspect ratio of √2 is divided into two equal halves parallel to its shortest sides, then the halves will again have an aspect ratio of √2. I. Reiche, S. Merchel, T. Ketelsen and O. Simon, 'Alc ixh xan; Zum zeichnerischen Kalkül Jan van Eycks'. In Ketelsen et al. 2005: 8–13, 12. In the eventual enlargement of, for instance the body of Christ, from the present drawing to the New York panel, this mechanism does not seem to have been rigidly followed, as the ratios largely varied from 1.43 to 1.48.
47. J. Sander, *Niederländische Gemälde im Städel, 1400–1500*. Frankfurt am Main, Verlag Philipp von Zabern, 1993: 54, fig. 19.
48. A particle of this pigment was taken from the back of the paper and subjected to elemental analyses and optical examination with PLM. Elemental analyses suggested the slight presence of phosphorus, which could indicate bone black. However, examinations of the particles under the microscope showed the typical birefringent fibres of linen primarily being stained with particles of indigo. The presence of indigo pigment has been confirmed by microchemical analysis (MCA).
49. Measurements on these areas with the digital microscope (see note 32), indicated that these indentations may be as deep as 45 µm.
50. S. Wülfert, *Der Blick ins Bild*, Lichtmikroskopische Methoden zur Untersuchung von Bildaufbau, Fasern und Pigmenten. Ravensburg, Ravensburger Buchverlag, 1995: 285.
51. Refractive indices of carbonate hydroxylapatite ($Ca_5(PO_4,CO_3)_3(OH)$, are slightly higher than those for the paper: $n\varepsilon = 1.626$, $n\omega = 1.629$.
52. C. Laroque, 'History and analysis of transparent papers', *The Paper Conservator*, 28, 2004: 17–32.
53. This bluish absorption may eventually have been caused by the presence of indigo pigment on the back of the paper (see note 48). Measurements were carried out by Dr H. Neevel of RCE, with fibre optic reflectance spectroscopy (FORS) using an Avantes AvaSpec–2048 spectrometer, measuring over the range of 380—750 nm, equipped with illumination from a Mikropak HFX-2000 xenon light source, and a AvaLight-Hal source.
54. Both at the J. Paul Getty Museum, Los Angeles: MS 37, fol. 106v, and MS Ludwig, IX 18, fol. 56v, respectively.
55. *Crucifixion*, illumination on parchment, 275 × 215 mm, *Breviarium Grimani*, Venice, Biblioteca Nazionale S. Marco, MS XI, 67 (lat. I.99), fol. 138v.
56. The only exception again being the well-known *Albergati* drawing in Dresden (Kupferstichkabinett Dresden, inv. no. C 775 (see Buck 1995: 185) and the painting in Vienna.

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