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The incarnation of carnation: a reconstruction of late Gothic flesh tones using the example of a Mary (1510) by the workshop of Ivo Strigel

A encarnação da carnação: uma reconstrução dos tons de pele do Gótico Tardio usando como exemplo uma Virgem (1510) da oficina de Ivo Strigel

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Abstract

It has been suggested that the prestigious carnations adorning late Gothic sculptures were crafted by the workshops' masters themselves. In fact, they are a complex structure of skillfully constructed and aligned layers. The Bern University of the Arts (HKB) in Switzerland utilized the example of a Mary (1510, Centrepiece of the retable of Grono, Rhaetian Museum Chur) by the established workshop of Ivo Strigel (1486–1514) to elucidate the distinctive characteristics of a late gothic carnation. For the first time, the HKB not only displays various binding media and pigments found in each individual layer, but also illustrates the stratigraphy and binder systems that can vary depending on the facial area. To gain a full understanding of the analytical results, colour reconstructions were used to assess the effect of different concentrations of protein (egg yolk) dispersed in linseed oil on the properties of drying, flowability, and surface gloss of the respective colour media.

KEYWORDS
Experimental art technology
Tempera grassa
Stratigraphy carnation
Wooden sculpture
Drying oil
Egg yolk

Resumo

Tem sido sugerido que as prestigiadas carnações que adornam as esculturas do Gótico Tardio seriam elaboradas pelos próprios mestres das oficinas. De facto, trata-se de uma estrutura complexa de camadas habilmente construídas e alinhadas. A Universidade de Artes de Berna (HKB), na Suíça, utilizou como exemplo uma escultura da Virgem (1510, peça central do retábulo de Grono, Rhaetian Museum Chur), da reconhecida oficina de Ivo Strigel (1486–1514), para esclarecer as características distintivas dos tons de pele do Gótico Tardio. Pela primeira vez, a HKB apresenta os diferentes aglutinantes e pigmentos encontrados em cada camada individual, e também ilustra a estratigrafia e os sistemas de aglutinantes, que podem variar consoante a área do rosto. Para compreender plenamente os resultados analíticos realizaram-se reconstruções de cor, avaliando o efeito de diferentes concentrações de proteína (gema de ovo) dispersa em óleo de linhaça nas propriedades de secagem, fluidez e brilho superficial conferido pelos diferentes aglutinantes.

PALAVRAS-CHAVE
Tecnologia artística experimental
Tempera gorda
Estratigrafia carnação
Escultura em madeira
Óleo de secagem
Gema de ovo

Introduction

The protagonist of numerous late Gothic altar pieces is the holy Mary. One of her attributes is a porcelain like skin and rosy cheeks. The achievement of lifelike flesh tones has constituted a significant artistic challenge throughout the history of painting. Nevertheless, the late Gothic period witnessed a significant advancement in the portrayal of the skin's surface, characterised by an even greater degree of realism. The objective of this study is to ascertain the technological secrets of the workshops that came to establish Mary's carnation, a pivotal figure in many late Gothic retables. The execution of her highly symbolic skin was hardly left to chance. To what extent has research in art technology advanced our understanding of the materials and techniques employed in the creation of this distinctive polychrome attribute?

The execution of flesh tones is a subject dealt with extensively in numerous treatises on medieval panel painting and book illumination, such as *Schedula diversarum Artium* (12th century) by Theophilus Presbyter, *Il libro dell'Arte* (1329) by Cennino Cennini or the *Liber Illuministarum* (around 1500). However, regarding the application, a distinction can be made between the functional requirements of paint media used on panels and those employed on the three-dimensional surfaces of sculptures. Few documented sources provide deeper insights into the materials and techniques used for creating flesh tones in medieval sculpture. A significant source is the *Solothurn Codex*, a collection of recipes from the central library in Solothurn, which has not yet been fully transcribed and published. The codex was likely composed around 1500 in southern Germany. This work is of particular interest as it provides comprehensive details regarding the production of paint media and the techniques employed in their application [1]. In contemporary research Theiss [2] has dealt particularly intensively with the subject of understanding the properties of paint media used for medieval carnations. With his hypothetical reconstruction of Saint Barbara (Workshop of Michel Erhart, 1490) based on scientifically analysed material samples, he gathers important insights into the painting technique of late Gothic carnation. Krebs [3, p. 203] documents with her observations on the carnations of Hans Multscher workshop-internal polychrome peculiarities about colour-defining layers, located below the topmost flesh tone. Hahn [4] encounters in his research that the coloration of carnations can even vary within the workshop. This conclusion was also drawn from numerous master's theses at the HKB Bern, where the art technological laboratory, Karolina Soppa and students of the specialization of paintings and sculptures have been involved in the focused study of flesh tones from a wide variety of workshops [5-6].

However, in comparison to other areas of polychromy, the number of published analytical studies on medieval carnation is significantly lower than one might expect. One of the reasons for this may be that the step of taking a sample from this delicate area is often not considered justifiable. Another reason is the turbulent history of many sculptures. Layers of original paint have been removed or conversely overpainted and are now hidden. Beyond that, our research showed, flesh tones are often classified as a conglomerate of the entire polychromy or are believed to be a homogeneous paint media with limited possibility of variations in pigments and binders used. Therefore, they are rarely considered as a unique specimen and detailed examinations are exceptionally rare. Thus, there are still numerous uncertainties regarding the art-technological implementation of flesh tones and, in particular, the paint systems used for them. Those circumstances led to a careful examination of a Mary (1510) attributed to the workshop of Ivo Strigel. Macro- and microscopic observations, stratigraphic analyses, and chemical imaging on cross-sections were carried out. The distribution and concentration of binder components was investigated using Fourier transform infrared spectroscopy (FTIR) and Focal plane array (FPA) imaging in combination with the SF4 derivatization technique. Inorganic components were determined using a scanning electron microscope with backscattered electrons and energy-dispersive X-ray (SEM-BSE-EDX). To gain a more comprehensive insight into the physicochemical and material properties of a "modified oil paint", used for the carnation of the Mary by Ivo Strigel, experimental colour reconstructions were carried out. The goal was to not only provide a visual depiction of the analytical results but also to use them to showcase the hypothetical properties of the analysed paint media, which include aspects such as drying, flowability, and surface aesthetics. Properties that were of particular interest regarding the impaired carnation of the examined sculpture. This study aimed to conduct a systematic test series with mixtures of sun-dried linseed oil and lead white, to which gradual amounts of egg yolk were added. By documenting the resulting characteristics, it was possible to identify the effects of varying protein concentrations on film formation, surface gloss, and viscosity of the films.

The stratigraphic examination of a late gothic carnation

Thanks to a collaboration with the Rhaetian Museum in Chur it was possible to study a late gothic altarpiece attributed to the workshop of Ivo Strigel, located in Memmingen, Southern Germany. In addition to domestic orders, lvo's workshop was geared towards exporting art [7, p. 123]. Strigel particularly supplied the diocese of Chur (in the fifteenth and sixteenth centuries, the present-day canton of Grisons, the Principality of Liechtenstein and South Tyrol were part of the diocese) with numerous altarpieces between 1486 and 1514. Nearly 30 completely preserved retables, altar fragments and individual figures can be linked to his workshop in this region [8, p. 10]. These circumstances made it possible to examine a flesh tone under workshop conditions and with an extended amount of time, a factor that often sets limits when examining sculptures in churches or exhibitions. The most significant sculpture in the shrine, Mary, was selected for this purpose. Her carnation was particularly suitable for this endeavour because it was affected by aging and previous interventions, as shown in Figure 1. These circumstances resulted in numerous areas exhibiting clearly visible stratigraphy, thus facilitating sampling.

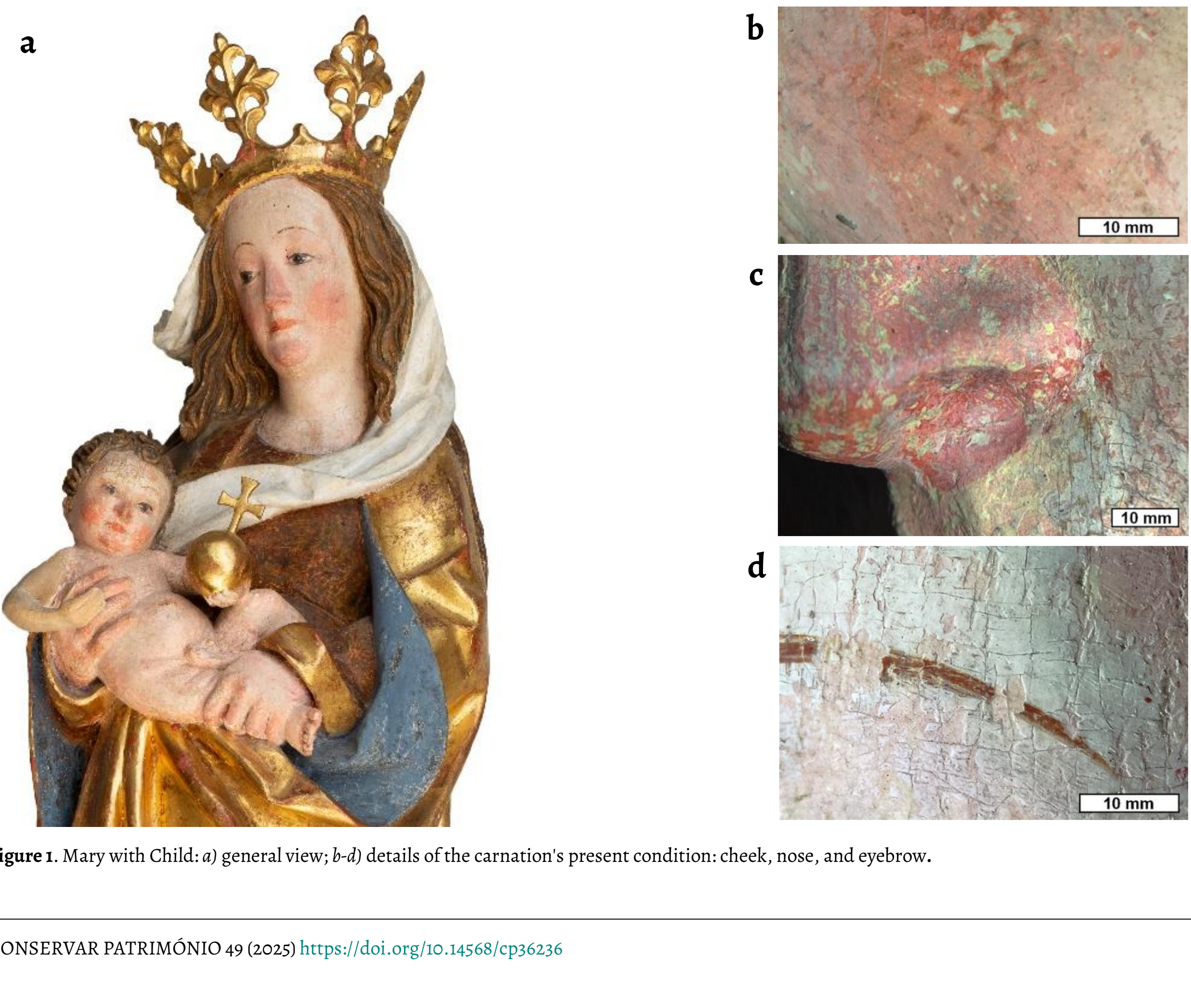

Figure 1. Mary with Child: *a)* general view; *b-d)* details of the carnation's present condition: cheek, nose, and eyebrow.

Method

A combined and complementary application of methods was target-aimed to create a maximum amount of information. Starting with aligned imaging methods, followed by a macro- and microscopic documentation of the painting technique, the examination was completed with spectroscopic analytics of selected samples. One challenge in spectroscopic analysis with FTIR is the spectra of oil-based colour samples. The presence of overlapping bands can make interpretation difficult. This applies especially to the prominent band of lead white which, due to signal interference can overlap the protein bands. In order to depict low-protein contents in oily binders, samples were derivatized with sulphur tetrafluoride. The derivatization method can eliminate the spectral band overlaps of carboxylates, as stated by Zumbühl et al. [9]. This improvement allows for the detection of low concentrations of proteins in oil-based systems [10]. However, it is still impossible to determine the specific type of protein present. Despite this, the concentration in micro samples can be estimated by analysing the relative signal intensities of the ester band (nC=O) in the oil and the amide I band of the protein. Since proteins are distributed heterogeneously, the concentration was also approximated by comparing FTIR-FPA images of reference samples with a defined protein concentration [10]. Inorganic components were determined using SEM-EDX.

Preliminary summary of the stratigraphy

The analysis of Maria's skin tone revealed the presence of a total of five different layers. However, the skin tone's stratigraphy is structured in four layers as shown in Table 1, Figure 2 and Figure 3. Layer three (not analysed) and four are applied exclusively to specific areas.

Table 1. Terminological classification of analysed binder systems and pigments in respective layers.

Description	Terminological classification		Binding media	Pigments
Light white-pink layer	5	Skin tone	Oil Protein 2-5 %	Lead white, cinnabar
Pure binder layer locally applied	4	Isolating layer	Protein based small oil content	none
Red shade locally applied	3	Accentuations	×	×
Pink layer with warm undertones	2	Colour defining preparatory layer	Protein 90 % Oil 10 %	Cinnabar, lead white, red lake pigment
Porous white layer	1	Primer	Protein 90 % Oil 10 %	Calcium carbonate

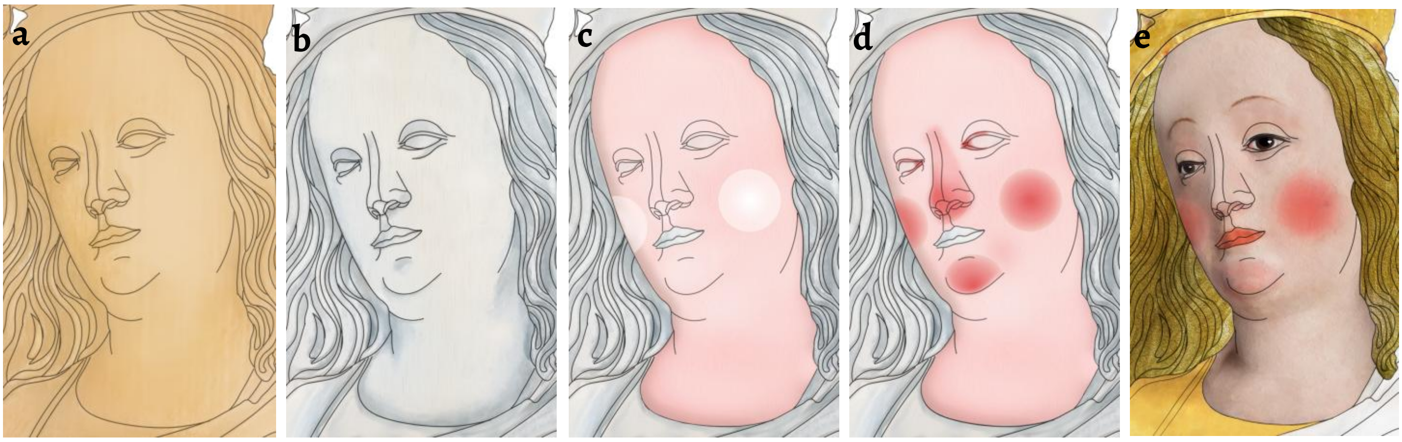

Figure 2. Stratigraphic implementation of the layers *a)* wooden support *b)* primer *c)* pink layer; *d)* locally applied red accentuations *e)* flesh tone.

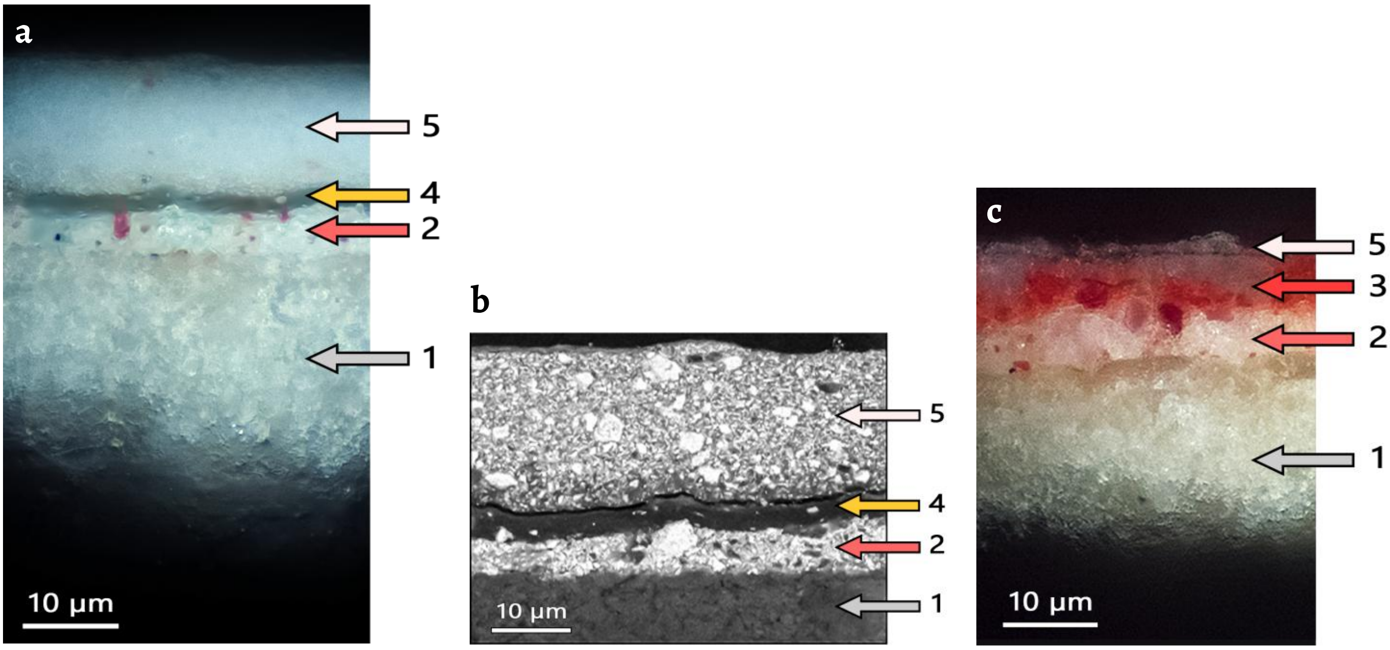

Figure 3. Cross-sections: *a)* forehead (VIS-BF xpol); *b)* forehead (SEM-BSE 2000× 20kV 100 pA 40); *c)* nose (VIS-BF xpol) with red accentuation and missing isolating layer.

Results of visual and analytical examination

The following descriptions illustrate the stratigraphy of Mary's carnation chronologically.

Wooden support and isolation layer

The wooden support was carved from lime wood, determined by a wood fibre analysis of a thin section sample. An isolation of the support could not be determined analytically but is visible with the stereo and digital microscope as a yellowish matrix lying over the wood fibres.

Primer

A single layer of primer, approximately 45 µm thick, was applied to the entire face of the sculpture (Figure 2b). The primer is noticeably thinner around the finely carved eyes and almost translucent on the lower eyelids. Since none of the cross-sections include the support, it cannot be ruled out that there are multiple layers of primer. The primer is composed of marine calcium carbonate with coccoliths and a binder that contains protein with a low amount of oil. Caused by a relatively low binder content, the primer exhibits weak binding. The FTIR measurement of the derivatized microsample indicates a ratio of approximately 90 % protein and 10 % oil. Adding an oil additive resulted in a more manageable, higher viscosity an extended drying period and furthermore reduces the absorbency of overlaying layers [11, p. 14].

Pink layer

The entire face, except for the lips and cheeks, has been coated with an opaque layer (9-10 µm) of a pink colour (Figure 2c). Raman spectroscopy and SEM identified that this shade is achieved by a mix of cinnabar and lead white with proportions of a red lake pigment, precipitated on the basis of calcium carbonate. The binder, identified by FTIR analysis, matches that of the primer.

Locally applied red shades

Red circles, defining the rosy cheeks, were applied using a vibrant red-orange paint media. Further, it was applied locally to the nose, chin, and eyes (Figure 2d). Although the paint media is thinly applied and highly saturated, it has a translucent character with high opacity. Analytical data shows that this layer is also aqueous bound and that there is no mixing with the pink-coloured layer during application. Its morphological character indicates that it is likely a blend of cinnabar and red lake pigment, possibly with the inclusion of lead white. This indicates a potential correlation with the previously applied pink layer.

Layer of binding media

A protein layer with a low oil content was detected above the pink layer using FTIR-FPA. Although this layer cannot be identified microscopically, it is clearly visible in the UV-fluorescence image of the cross-sections as an area without inherent fluorescence. Additionally, in the SEM-BSE image, it is distinguishable as a black gap (Figure 3b). Even if it is not localized on the primer as is typical, the function of this layer can be classified as an isolation layer (glue size), with the task of preventing the oil-based binding media of the flesh tone from penetrating deeper layers, as documented in historical sources [12]. Besides its sealing effect, the binder also provides additional support for the subsequent oil-based layer. Interestingly, this layer was applied only to selected areas of the face, specifically the cheeks, forehead and neck, while it is missing on the nose.

Flesh tone

A shade of white with a warm undertone was applied in varying thicknesses between 2-25 µm. The mixture is composed of lead white and cinnabar and completes the composition of the carnation. The lead white component was identified as a basic lead carbonate (2 $PbCO_3$•b$(OH)_2$). Cinnabar (HgS) was identified through SEM element mapping. Bone black was identified in the sample due to its phosphorus content using SEM-EDS. The function of the black pigment remains unclear, but it is recognizable in practically all cross-sections. The binder used is an oil-based mixture with an approximate protein content of 2-5 %. As shown in

Figure 4, the uppermost layer revealed a heterogeneous distribution of a proteinaceous binder, which was made visible by derivatizing a cross-section and a subsequent FTIR-FPA examination. Although the low protein content limits definitive conclusions, it is evident that it is not evenly dispersed in the system. Furthermore, ketones, the primary oxidation products of resins, were detected. Although these can also be formed by oils, a resin component cannot be absolutely ruled out for this layer.

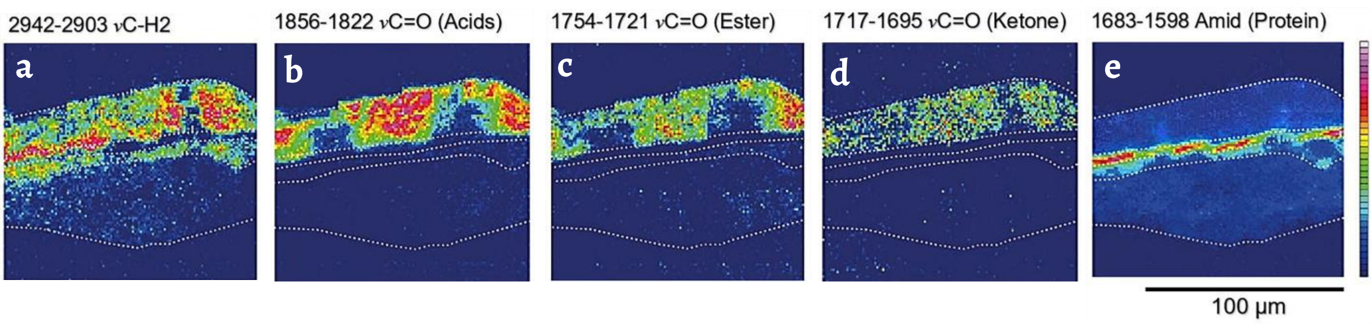

Figure 4. FTIR-FPA image of an SF4 derivatized cross-section. Showing a heterogeneous binder distribution of oil and protein in the topmost layer of the skin tone: *a)* 2942-2903 cm^{-1} $_{\nu}$C–H_2; *b)* 1856-1822 cm^{-1} $_{\nu}$C=O (Acids); *c)* 1754-1721 cm^{-1} $_{\nu}$C=O (Ester); *d)* 1717-1695 cm^{-1} $_{\nu}$C=O (Ketone); *e)* 1683-1598 cm^{-1} Amid (protein).

Art technological observations

The technological observations allowed the classification of three different application methods, illustrated in Figure 5. The topmost skin tone is first applied to the peripheral areas of the face, forehead, and neck. This is done with a highly opaque and impasto application of colour. Areas previously highlighted in red, such as the cheeks, chin, and nose, as well as the eye sockets, are initially omitted. The heavily opaque paint application on the forehead becomes increasingly translucent, starting at the eyebrow level and fading toward the upper eyelid, with the pink layer becoming increasingly visible. The eye sockets and the areas around the nasal wings, highlighted in red, are only covered with a thin white glaze to model reddish skin tones. This fading opacity and glazing process can also be observed around the chin and the cheek circles previously highlighted in red. The upper segment of the cheek circle is covered with a delicate white glaze so they remain recognizable. The opacity of the paint application becomes weaker towards the centre of the circle until it finally disappears completely, and the red setup becomes visible. A technical variation was used for the nose. Since no blocking isolation layer was applied here, the binder of the very thinly applied skin tone is now partially absorbed by the pink layer, creating a white shimmer on the surface, which creates the common reddish nose tip of late Gothic carnation.

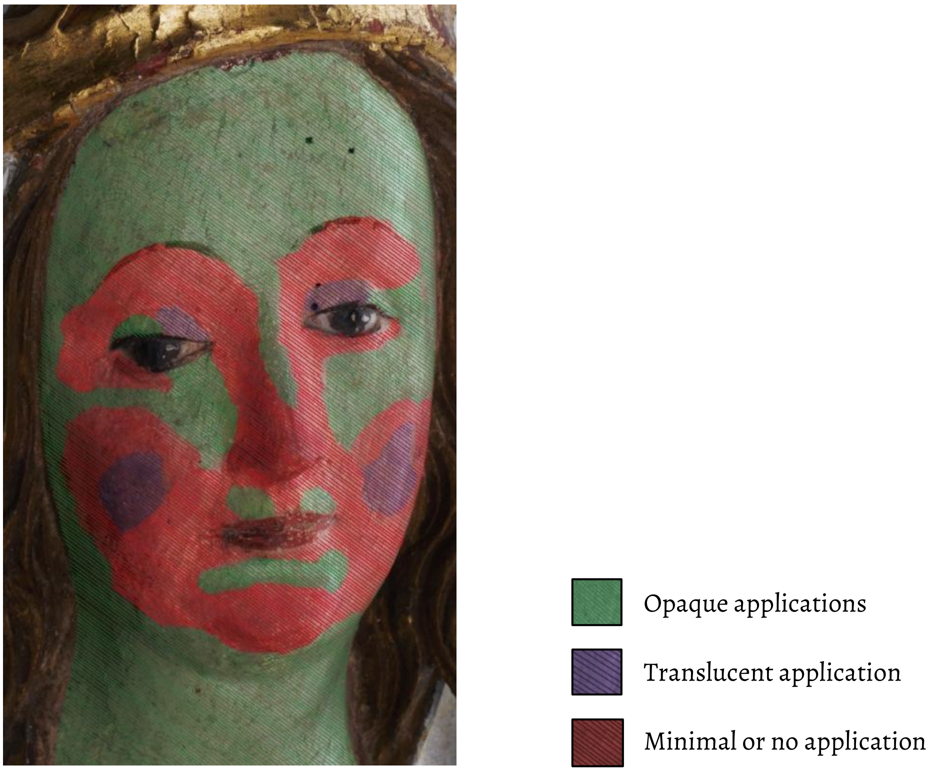

Figure 5. Mapping showing the different application techniques.

Reflections on the pink layer

One question regarding this stratigraphy is the technical function of the pink layer and the local accentuations. Do they influence the colour appearance of the overlying lead-white layer, or is its opacity such that it inhibits the visibility of the underlying pink layer? Moreover, if this is the case, what is their function? Due to the severely damaged paint layer, this question is challenging to answer visually.

When the function of the pink layer is placed in a technical context, the following conclusions can be drawn. If the construction of a skin tone begins with a reddish base or a coloured primer, the technical approach to the intended colour effect and modelling of the flesh tone is different than with methods using multiple colour systems. Reddish layers create a filter effect that lends a warm depth of light to even opaque white paint applications [13, p. 203]. In terms of technique, it is therefore possible to achieve cool white skin tones with opaque colour applications and warmer flesh tones with glazing layers. This method was able to accelerate the completion of carnations [14, p. 303] and fits well with the rapid working methods of late Gothic workshops. In the case of carnations that are constructed without a coloured base, reddened segments of the face are achieved differently. Either by applying light, transparent red glazes on a dry base skin tone or with a wet-on-wet dispersion or dotted incorporation of a red paint media into the white base skin tone. However, the function of systems with coloured underpaintings remains an interpretation of current observations, and its complete understanding still needs to be discovered. Is the form of a two-staged underpainting an isolated phenomenon, or does it represent a conceptual aspect of Strigel's carnations? If this is indeed the case, can they be attributed solely to the workshop's final creative period (1506-1512), or is it even limited to the production of export goods? A comparison with other carnations of Ivo Strigel's workshop could prove highly beneficial in identifying patterns in the technique and thus gain insight into the purpose of coloured underpaintings.

Experimental practical studies

Scientific analysis of Mary's topmost skin tone allowed to identify two binder components, their percentages in the system and pigment additions of lead white and cinnabar. The result for the binder is a mixed system consisting of oil with a low protein content of approximately 2 to 5 %. Small amounts of protein added to oil-based paint media have not yet been conclusively clarified. In order to classify the analytical data, 20 German-language recipe books from the period 1400-1550 were consulted [12]. It has been speculated that proteins may have been used to grind the pigments [15]. This has not yet been proven as a common technique from the sources examined, nor has this hypothesis been confirmed analytically. Therefore, based on the distribution of the protein in the material structure, it is assumed to be an additive to the oil. The use of egg yolk is likely, since this protein-containing material can be mixed with oils due to its emulsifying properties. Upon consideration of the chemical composition the incorporation of protein into the binder is a crucial factor in determining the technical properties of the paint media. In order to further investigate this question, a systematic series of experiments was carried out. However, the aim is not to simulate a historical paint media, but rather to understand the possible effects of such mixed systems. It can be reasonably assumed that the protein had an impact on the texture of the paint media. The observations of Mary's carnations demonstrates that the paint media has a high degree of opacity and allowing both pastose and translucent applications. But what are the physical and optical qualities of such a paint media? These are questions that are of great interest for the present work, due to the damaged surface of Mary's carnation. The influence of the protein on the properties of an oil-based paint was simulated by varying the pigment, linseed oil and protein concentrations.

Questions

Prior to the test series, questions were defined for each analysed component in the system. In summary, these questions fall into three main categories as illustrated in Table 2.

Table 2. The three main research questions and their respective primary issues.

Drying	Viscosity	Surface appearance
Influence of protein on speed of drying	Amount of protein necessary to achieve change in viscosity	Effects of different protein concentrations on optical properties
Difference between film formation and chemical drying	Influence of viscosity on surface appearance and drying	Influence of protein on surface appearance
Drying time of a paint media matching the analysis (Protein 2-5 %)	Viscosity of a paint media matching the analysis (Protein 2-5 %)	Surface appearance of a paint media matching the analysis (Protein 2-5 %)

Materials

The components of the test series are based on the analytical results of the topmost skin colour of Mary, which were lead white and cinnabar in an oil-based binder with a protein content of approximately 2-5 %. Since cinnabar was only analysed in very small quantities and presumably has a primarily colour-influencing property on the binder, it was not included in the test series. Consequently, the test series were to be carried out with three components, namely lead white as a dry pigment, sundried linseed oil and an addition of protein. Since the specific protein type in the binder was not identified, examples from several studies in literature that examined protein additions in binders of carnations using GC-MS [2, p. 105; 16, p. 317ff] were consulted. Both analyses identified egg yolk as the protein component in the binder. Further egg yolk was chosen for its emulsifying properties and its protein content of 16 % [17, p. 282]. The protein content for the mixtures was therefore calculated based on this percentage. Accordingly, the stated protein content does not refer to the amount of egg yolk in a mixture, but to the proportion of protein it contains. Only organic eggs were used for the test series as the feeding of yolk-colouring pigments is prohibited [18, pp. 12-13]. Before processing, the vitelline membrane surrounding the yolk was removed and passed through a sieve to remove inclusions and blood clots. For the pigment a synthetically produced alkaline lead carbonate ($2\,PbCO_3{\bullet}Pb(OH)_2$) with a sieve residue < 44 µm was chosen (#46000 Cremnitz White by Kremer Pigments). The use of a pre-treated linseed oil appears likely, as the paint media would otherwise dry very slowly, which would significantly impede the efficiency of the work process. As early as Theophilus in the eleventh century [19, p. 60] and Cennini in the fourteenth century [20, p. 61] observed that placing linseed oil in the sun for a period of time would result in a more suitable consistency for painting. Therefore, a sun-thickened linseed oil, was used for the test series, which was produced by the slow absorption of oxygen in the sun (#73055, Linseed Oil, cold-pressed and sun thickened by Kremer Pigments).

Preparation

The lead white pigment first was submerged in sundried linseed oil. Then these mixtures were processed by grinding them on a glass plate for 15 minutes with a pestle until a homogeneous texture was achieved. Initial tests established the ideal ratio of lead white to linseed oil for creating a paint media that achieves uniform pigment saturation, ensuring good opacity and a consistency that is easy to distribute. The most effective results were obtained with a mix of 28 % linseed oil and 72 % lead white. Based on this ratio, ten different paint films were produced, each containing increasing protein content ranging from 0.15 to 5 %. Egg yolk was gradually added with a micrometric syringe (Pipet-Lite XLS), folded under with a spatula and again grinded for another 10 minutes. The paint media then was applied to a microscope slide with a film applicator (Type 284 Bird) in a layer thickness of 100 µm. Additionally, a brushstroke was drawn with a 1 cm hog hair paintbrush on a microscope slide, to evaluate if the paint media could be used in both opaque and transparent applications.

Method

The films were dried in light boxes and in daylight. The light box simulated an irradiation with mixed light with a light intensity of 5800 lm/m^2 and a UV component of 557 mW lm^{-1}. The temperature 10 cm above the samples varied between 45 °C and 15 °C, the relative humidity ranged between 32 to 45 %. The reference test series was dried indoors beside a window, with an exposure of 3.5 hours of direct sunlight per day. Temperatures ranged from 6 to 18 °C and a relative humidity between 45 to 56 %. Changes caused by drying were observed by monitoring the weight to assess the progress. This method is possible due to the technological uniqueness of linseed oil in its chemical drying. In this process, the binding agent solidifies through a chemical process known as auto-oxidation. Drying is initiated by a radical chain reaction, formed by atmospheric oxygen or UV-light, that can be defined by different reaction steps. These reactive particles accelerate the oxidation process which leads to a significant absorption of oxygen that increases the size of the molecules [21, p. 6]. The paint films were weighed every 24 hours, selected films in more frequent intervals (1, 2, 3, 6, 12 and, 24 h) on a high precision scale. Changes in weight were documented gravimetrically to allow conclusions about the drying process of paint films with different protein concentrations. Film formation was evaluated haptically by touching the surface. Observations on the viscosity and surface appearance of the films were evaluated in terms of their utilization as a paint media based on the technical observations of Mary's carnation.

Results and discussion

Drying

The series of samples dried in the light box shows a steady increase in weight within the first three hours, reaching a maximum of 1.5 mg after 3 hours. After that a linear weight loss of about 0.25 mg per day occurs until the initial weight is reached after 5 days. The films dried in daylight however show a very heterogeneous drying process overall. In the first six hours, eight out of ten colour films show an increase in weight, but at different rates. After 24 hours, all samples show a steady but minimal loss of weight, which over the next eight days is characterized by a relatively flat curve with an average decrease of 0.05 mg per day.

The comparison to films without protein shows that egg yolk produces a more homogeneous drying with fewer fluctuations in weight increases and decreases. Nevertheless, the tests showed that the addition of protein does not have a significant effect on the speed of oxygen uptake. But if we evaluate the speed of film formation, however, there are clearer effects. Judged by haptic criteria, all films with a protein content of less than 1 % are touchable after 12 hours, above 2.5 % even within 1.5 hours without being tacky. This is around 5 times faster than the reference test series with the same lead white content but without egg yolk. It is important to differentiate between chemical drying and film formation. A comparison of film formation and changes in film weight has shown that there is no relationship between these two parameters. This means that the point at which a film is surface dry cannot be associated with a specific event such as weight loss. In particular, films with high protein contents show a drastically reduced drying time, which seems to be related to the higher water content of these films coming from the egg yolk. An explanation for these phenomena could be the partial transition from a purely chemical to a partially physical drying process defined by water loss in the initial phase.

Viscosity

Even the addition of minimal amounts of protein had an immediate effect on the viscosity of the mixtures (Figure 6). At 0.15 % protein in the binder, there is a slight reduction in flowability. At 0.35 %, flowability is significantly reduced. At a protein content of 0.75 % in the binder, the first thixotropic properties of the paint appear. This indicates that high viscosity can be temporarily reduced by shear forces, such as those generated during the application with a paintbrush. At a concentration of 1.65 % protein content, the fluidity of the mixtures is practically eliminated and the paint becomes highly viscous and honey-like. Even highly pastose brush applications retain their structure until drying. At concentrations above 3.5 % protein, thixotropic properties are no longer present and the mixtures becomes highly viscous and difficult to apply with a paintbrush.

Surface appearance

The addition of protein has a particular effect on the 100 μm films. These appear slightly glossier than films without egg yolk, but still fall into the semi-matte category. Pastose applications with a paintbrush have a porcelain-like gloss. The level of gloss increases continuously up to a protein concentration of 2 %, after which the effect is reversed, and all forms of application become increasingly matte as shown in Figure 7. Above 5 %, both film and brush applications appear very dull. All formulations are very yellowish due to the addition of egg yolk. However, this effect disappears within a few hours in the light box. Even when stored at the window, the yellow tint disappears completely after a few days. Unlike the yellowing caused by linseed oil, this loss of colour is not reversible [22].

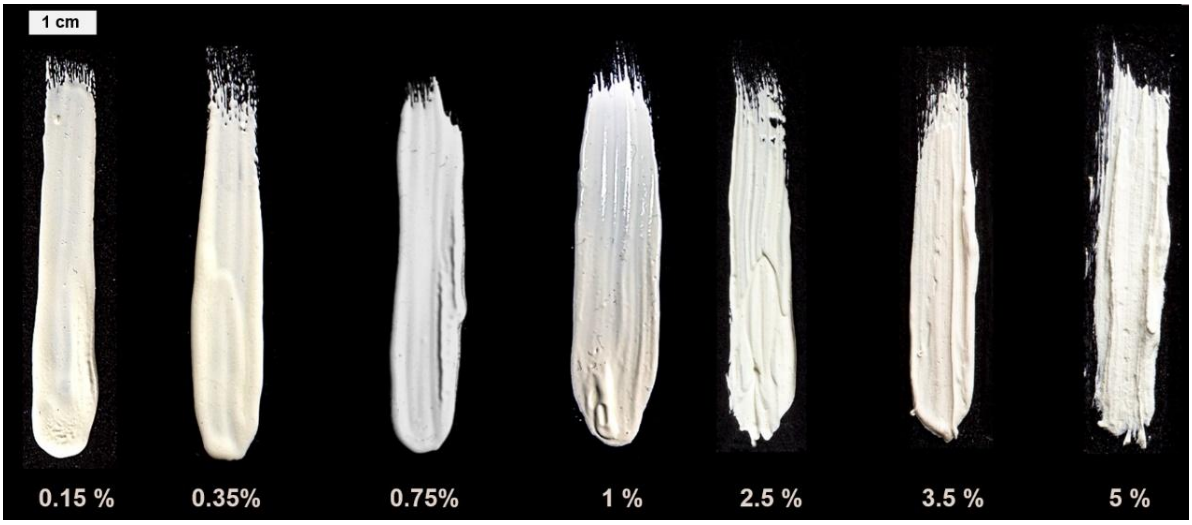

Figure 6. Changes in viscosity of mixtures with different protein concentrations (%): 0.15, 0.35, 0.75, 1, 2.5, 3.5, and 5.

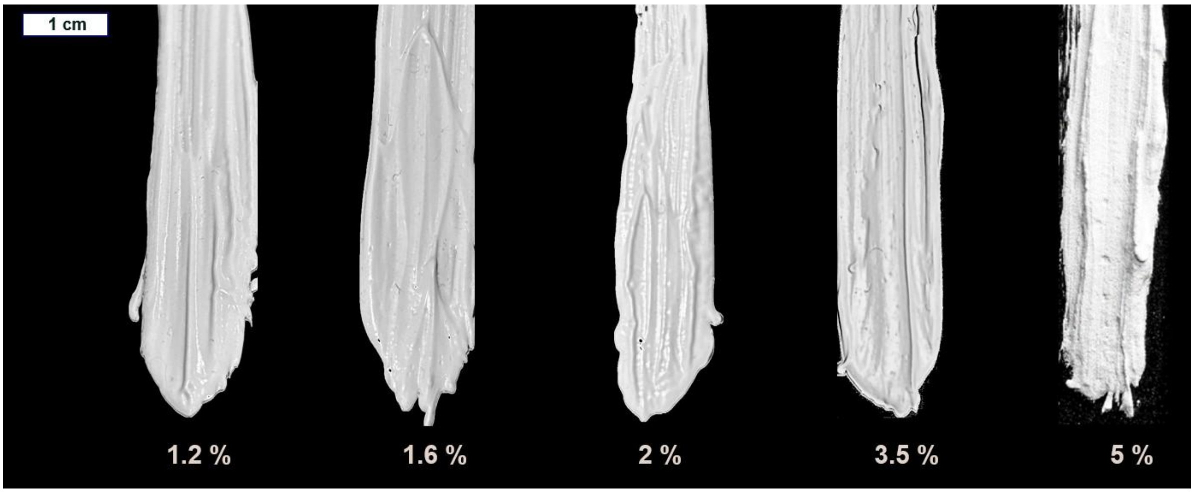

Figure 7. Changes in gloss level of paint media with different protein concentrations (%): 1.2, 1.6, 2, 3.5, and 5.

Hypothesis on the original surface aesthetics of Mary

The practical experiments have shown that the properties of oil colours can be modified in various ways by adding small amounts of protein. In view of the sophisticated painting technique observed on the sculptures by Ivo Strigel, it can be assumed that the workshops had specific requirements for their colours. By specifically modifying these properties, the artists were able to vary the workability and thus achieve different visual effects. If we were to hypothetically reconstruct the surface appearance of Mary's carnation, by concluding the gathered results it may have consisted of contrasting areas with different optical impressions. It would be possible to achieve smooth and glossy surfaces by finely dispersing thicker applications with a paintbrush. Conversely, it is conceivable that translucent white applications may result in a rather matte to satin-matte surface. This results in a juxtaposition of semi-gloss and glossy surfaces.

Conclusions

The combination of spectroscopic analysis and experimental art technology facilitated a significant reconstruction of the stratigraphic setup of Mary's carnation. The documentation revealed that a red underpainting was applied to the entire face, followed by two localized, protein-bound layers: the red accentuations and an isolation layer. This detail is particularly interesting from a technical perspective and enhances our understanding of the relationship between the final, predominantly oil-based layer and the two preceding preparatory layers, which serve as a foundation for achieving various skin tones. This reveals a sophisticated system for creating Mary's flesh tone, highlighting the artistic mastery of the workshop. Through the analytical examination of the samples, it was estimated that the protein content in the predominantly oil-based binder ranged from 2 to 5 %. This estimation facilitated the formulation of a test series derived from the analysed components of Mary's carnation. Consequently, it was possible to assess the drying times and film-forming properties while also documenting viscosity levels and rheological characteristics. This comprehensive analysis enhanced the understanding of the performance of the various mixtures as paint media. The observations from the test series indicated that protein concentrations between 1 and 3 % hypothetically are suitable as a paint media in terms of surface aesthetics, workability and viscosity, whereas the 5 % concentration proved inadequate without further modification. The study also highlighted the limitations of advanced analytical techniques, along with the time-consuming nature of developing a comprehensive understanding of the paint media used. While an approximation of the paint's characteristics can be achieved, a subsequent step remains necessary: the practical application of the paint on a three-dimensional surface. For this purpose, a wooden 3D model of Mary's face has been created. Initial tests indicate that this step presents its own challenges, such as visible brush marks on the surface and uneven distribution of the colorant over the topographical features. Theiss and Faldley [2, 23] have suggested initial solutions by using a fan brush dampened with water to help achieve a more uniform distribution of the colorant. However, many questions remain unanswered, and further research is needed to attain an even more precise approximation of late Gothic carnations.

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