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Use of the MA-XRF Technique in Authenticating Guignard's Artwork Recovered by the RJ Civil Police

Utilização da Técnica de MA-XRF na Autenticação de Obra de Guignard Recuperada pela Polícia Civil RJ

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ABSTRACT

Artworks are frequently implicated in the commission of crimes of money laundering, fraud, corruption and robbery/theft. On August 10, 2022, *Operação Sol Poente* (*Operation Setting Sun*), launched by the Civil Police of Rio de Janeiro, recovered seventeen artworks stolen from the *Boghici Collection*. Among them was the *Menino* [*Boy*] (1935), by Guignard. For this reason, forensic examinations were conducted to verify the authenticity of the recovered artworks. Therefore, macro X-ray fluorescence scanning (MA-XRF) was employed as a portable and non-invasive technique to obtain elemental maps of the chemical composition present in the paint layers. The objective of this study was to demonstrate the potential of the MA-XRF technique in the context of a high-profile criminal investigation. Elemental mapping was conducted using the portable MA-XRF system, model CRONO (Bruker), on both the authenticated and unauthenticated artworks. The resulting elemental distributions exhibited significant similarities, indicating consistency in the materials and techniques used in their production. These results indicate similarities in the creation process and materials of the paintings. Although the authentication of artworks remains a complex and multidisciplinary process, the results of this study underscore the value of MA-XRF as a forensic tool capable of providing valuable insights in the resolution of forensic cases.

keywords artwork authentication, MA-XRF technique, forensic art analysis

RESUMO

Obras de arte são notoriamente utilizadas no cometimento dos crimes de lavagem de dinheiro, estelionato, corrupção e roubos/furtos. Em 10 de agosto de 2022, a *Operação Sol Poente*, deflagrada pela Polícia Civil RJ, recuperou dezessete obras de arte subtraídas da *Coleção Boghici*. Entre essas obras, estava a pintura *Menino* (1935), de Guignard. Sendo assim, tornaram-se necessários os exames periciais de autenticidade. Dentre as técnicas utilizadas está o macro mapeamento por fluorescência de raios X (MA-XRF), que permite obter imagens da distribuição de elementos químicos presentes em diferentes camadas da pintura, de forma portátil e não invasiva. O objetivo deste trabalho foi demonstrar o potencial da técnica de MA-XRF em um caso criminal de grande repercussão. Utilizou-se um equipamento portátil de MA-XRF, modelo CRONO/Bruker para analisar a pintura apreendida e autêntica. Os mapas elementares, obtidos a partir das análises da obra questionada e de obras padrões, apresentam grandes semelhanças na forma de distribuição dos elementos. Esses resultados indicam similaridades no processo de criação e materiais empregados nas pinturas. Embora a determinação da autenticidade de uma obra de arte seja um processo complexo, que envolve diferentes exames, o MA-XRF vem se destacando por proporcionar informações valiosas na elucidação de casos forenses.

palavras-chave autenticação de obras de arte, técnica de MA-XRF, análise forense de arte

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Introduction

The Brazilian arts market has been growing in recent years, leading the purchase of works of art in the world in the 1st half of 2024, according to the most internationally renowned report for this sector of the economy (McAndrew, 2024). However, the forgery of artworks, used in the commission of crimes of copyright infringement and embezzlement, has shown a significant increase in recent years. Currently, it is estimated that 30% to 40% of all existing works of art are false or misattributed, generating a global scourge that generates around six billion dollars annually (Anjos, 2017; Faria & Puglieri, 2011).

These forgeries are produced using increasingly sophisticated methods and techniques, presenting constant mutations that aim to erase traces of the crime in response to the evolution of measures designed to combat it. Notoriously, this type of crime shows a growing trend, considering the spread of auctions of works of art over the internet, where it is easier to sell them at precarious valuations (Brunello et al., 2021). Representatives of several Brazilian artists, such as Di Cavalcanti, Tarsila do Amaral, Djanira, Burle Marx, Enrico Bianco, among others, have been publicly demonstrating against fakes traded in online auctions at prices well below market values (Lucena, 2019).

These data highlight the importance of implementing procedures for forensic examinations of cultural assets in the country's scientific police, one example is the transdisciplinary methodology of forensic analysis of paintings, developed jointly by the Criminal Experts of the Scientific Police of Rio de Janeiro and the Professors/Researchers of the Instrumentation and Computational Simulation Laboratory (Liscomp) at the Federal Institute of Rio de Janeiro (Thaumaturgo, Souza, Fialho, et al., 2024).

As an example of a real criminal case in which the aforementioned methodology was essential for the elucidation of the case, we can mention *Operação Sol Poente* (*Operation Setting Sun*), launched on August 10, 2022 by the Civil Police of the State of Rio de Janeiro, in which seventeen paintings were recovered, taken from the *Jean and Geneviéve Boghici Collection* through the practice of fraud, false imprisonment and bodily harm. Among them, supposedly was the *Menino* (1935), which means *Boy* in Portuguese, by Alberto da Veiga Guignard (Thaumaturgo, Souza, Liarth, et al., 2024). Although the provenance of this painting has been very well documented over the years, the criminal abduction led to its disappearance for a few months. Therefore, expert authenticity examinations became necessary.

Technological advances, especially in the last two decades, have enabled the emergence of different portable instruments for the physicochemical investigation of paintings (Miliani et al., 2010; Rosi et al., 2019). In addition to allowing accurate information on the composition, structure, materiality, and regrets present in artwork, these instruments can carry out *in situ* and non-invasive analysis (Campos et al., 2019).

Among the techniques currently available for investigating paintings, those that produce images, such as macro X-ray fluorescence scanning (MA-XRF), stand out. It is a technique that allows obtaining images of the distribution of chemical elements present in more superficial layers and underlying layers of the painting, allowing the inference of materials such as pigments, fillers, and ground (Alfeld & de Viguerie, 2017; Pereira et al., 2021; Van der Snickt et al., 2018). The obtained elemental maps provide insights into the creation process of the painting and its history of interventions (Nardes et al., 2023; Parma et al., 2023). Furthermore, because the results obtained are images, they facilitate the understanding of the different stakeholders involved in a forensic examination of paintings, such as judges and lawyers.

The objective of this work was to demonstrate the applicability and potential of the MA-XRF technique in a real high-profile criminal case, in which a work of art was authenticated, helping to preserve the historical, artistic and cultural heritage of our country.

Materials and methods

This section describes the procedures adopted to evaluate the authenticity of the artwork recovered during operation. Figure 1 presents the questioned painting, *Menino* (1935), supposedly attributed to Guignard.

This painting, shown in Figure 1, was compared with two reference works by the same artist, shown in Figure 2. Both reference paintings — Natureza Morta (1952) and Paisagem de Sabará (1952), meaning *Still Life* and *Landscape of Sabará* — were produced using oil on wood and belong to the collection of the *Museu Nacional de Belas Artes* (Brazil), shown in Figures 2(a) and 2(b), respectively.

Figure 1 - Artwork recovered during the operation and questioned as to its authenticity, *Menino*, 41 × 33 cm, (1935).

Figure 2 - Standard artwork produced by the author Guignard, using the oil on wood technique, made available by the *Museu Nacional de Belas Artes*: (a) *Natureza Morta*, 40 × 50 cm, (1952) and (b) *Paisagem de Sabará*, 50 × 60 cm, (1952).

(a) (b)

The MA-XRF analyses were carried out using instrument CRONO model from Bruker, which has an X-ray tube with an Rh anode and SDD detector. The system allows scanning an area of 450 mm × 600 mm (Alberti et al., 2017). For the measurements of the paintings, was used the 1 mm collimator and tube operate with a voltage of 40 kV and a current of 200 μA. Under these conditions, for every 1 mm of the painting, a spectrum was collected per 40 ms.

For the image reconstruction process, fitting models were built from the sum spectra of each cube's pixels obtained during the measurement of the painting. The fitting models were elaborated in the range from 1 keV to 29 keV using the PyMca software (Solé et al., 2007). This region was chosen to allow the observation of the characteristic K lines of the elements Cd and Sn. In the region between 16 keV and 21 keV, phenomena such as peak sum and Compton and Rayleigh scattering were not considered in the model elaboration. The model was elaborated using a SNIP background algorithm, and parameters (detector, beam, peaks, peak shape, attenuators, and matrix) closest to the experiment's conditions were inserted in PyMca.

The evaluation of the spectra of each pixel by the fitting model was carried out in the datamuncher software (Alfeld & Janssens, 2015), where the image data cube's stitching and correlation processes were performed.

The fitting-based evaluation performs a deconvolution of the spectra, allowing the generation of more precise elemental maps, as it enables the identification of the contribution of each element in cases where peaks overlap. For example, in the case of overlapping between the K lines of potassium (≈ 3.33 keV) and L lines of cadmium (≈ 3.40 keV). The method also allows for the deconvolution of cases of overlapping of Kβ and Kα lines. This situation is common in consecutive periodic table elements such as chromium/manganese and iron/cobalt.

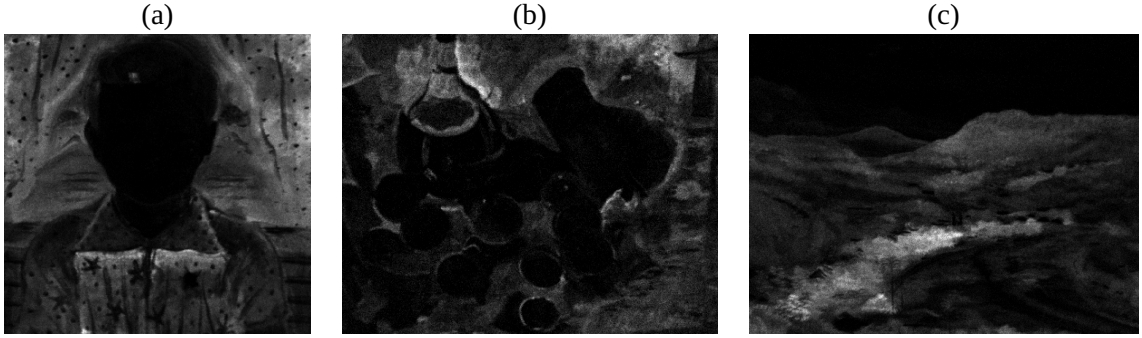
In addition to the two standard works used in the direct comparison, the results obtained in the analyses of the questioned work were also compared with the works examined in the *Guignard Research* (Moresi & Neves, 2012), as presented in the Supplementary material section.

Results and discussion

The elemental maps, obtained from the analysis of the questioned painting, Figure 1, and the standard paintings, Figures 2(a) and 2(b), showed significant similarities in the distribution of elements.

For example, the chromium (Cr) maps were identified in the green regions of all three paintings, Figure 3.

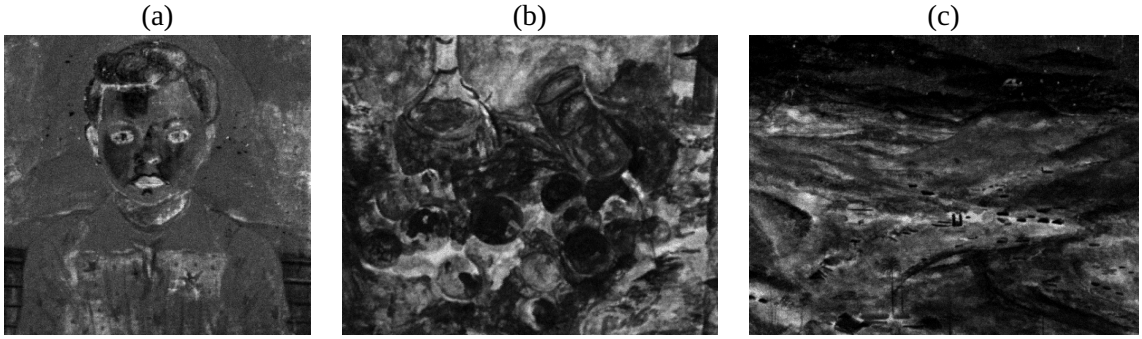
Figure 3 - The chromium (Cr–Kα and Kβ) map was observed in the green regions of the three paintings, in the following sequence: (a) *Menino*, (b) *Natureza Morta*, and (c) *Paisagem de Sabará*.



This element Cr is commonly associated with the green chrome pigment (Cr_2O_3) or Viridian ($Cr_2O_3.2H_2O$) (Kajiya et al., 2025). The maps, Figure 3, indicate that the chromium-containing material, in addition to appearing in green regions, was also visible in regions of other tones, as in the case of the brown background of the paintings *Menino* and *Natureza Morta*, and in the brown hills of the painting *Paisagem de Sabará*. The use of pigment with chromium in regions of another tone indicates a mixture of green paints with other tones. These results from the chrome elemental maps indicate similarities in the creation process of the artworks, which use a mixture of green pigments to achieve different shades, for example brown.

The maps of barium (Ba), calcium (Ca), zinc (Zn), and lead (Pb) appear in large areas of the three works, Figures 4-7, respectively. This distribution indicates the use of materials containing these elements in the ground and fillers (Balard & Papirer, 1993).

Figure 4 - The barium (Ba–Lα and Lβ) map was observed in extensive regions of the three paintings, in the following sequence: (a) *Menino*, (b) *Natureza Morta*, and (c) *Paisagem de Sabará*.



Fillers are finely divided solid substances that are incorporated into pigment and can enhance the properties of the system in terms of density, porosity, permeability, and durability (Pfaff, 2022).

In the case of lead, it is common to use pigments containing this material in the imprimatura layer of the canvas. Materials with Ba, Ca, and Zn can also be used in the imprimatura or as fillers for paints. Substances associated with these elements commonly include barium sulfate ($BaSO_4$), calcium carbonate ($CaCO_3$), and zinc white (ZnO) (Gaber, 2012).

The elemental map of iron (Fe) was observed in the three works, Figure 8. This element is commonly associated with the pigments red ocher (Fe_2O_3), sienna brown (Fe_2O_3 + clay + silica), black magnetite (Fe_3O_4), and green earth $K[(Al, Fe^{III}), (Fe^{II}, Mg)](AlSi_3, Si_4)O_{10}(OH)$.

Figure 5 - The calcium (Ca–Kα and Kβ) map was observed in extensive regions of the three paintings, in the following sequence: (a) *Menino*, (b) *Natureza Morta*, and (c) *Paisagem de Sabará*.

(a) (b) (c)

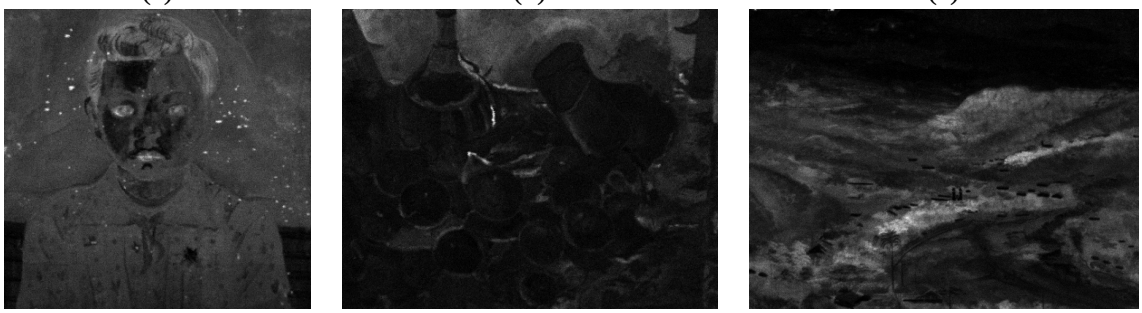


Figure 6 - The zinc (Zn–Kα and Kβ) map was observed in extensive regions of the three paintings, in the following sequence: (a) *Menino*, (b) *Natureza Morta*, and (c) *Paisagem de Sabará*.

(a) (b) (c)

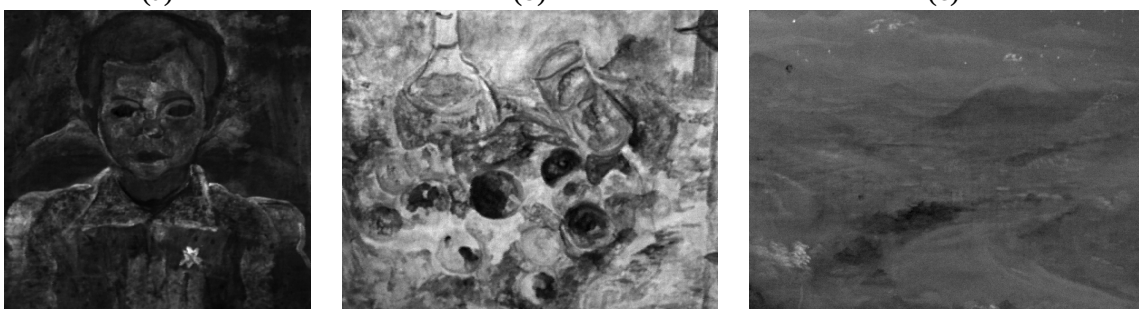


Figure 7 - The lead (Pb–Lα and Lβ) map was observed in extensive regions of the three paintings, in the following sequence: (a) *Menino*, (b) *Natureza Morta*, and (c) *Paisagem de Sabará*.

(a) (b) (c)

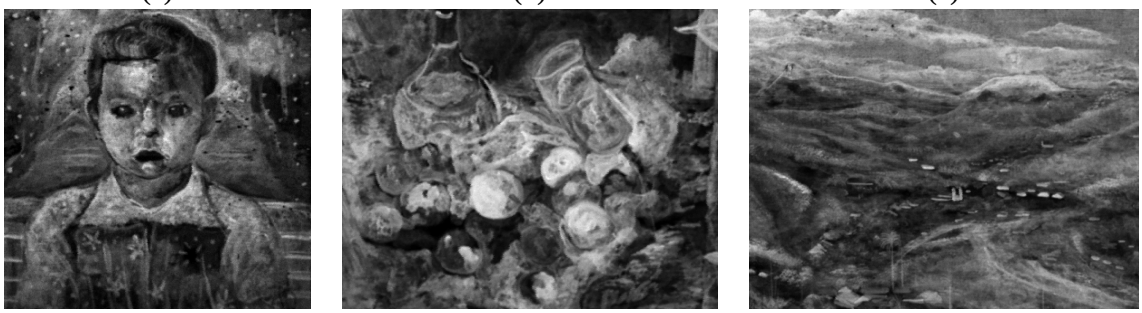
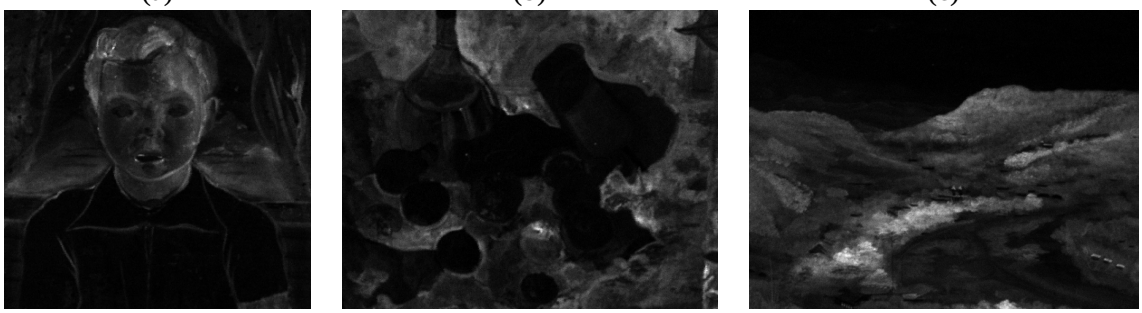


Figure 8 - The iron (Fe–Kα and Kβ) map was observed in regions of the three paintings, in the following sequence: (a) *Menino*, (b) *Natureza Morta*, and (c) *Paisagem de Sabará*.

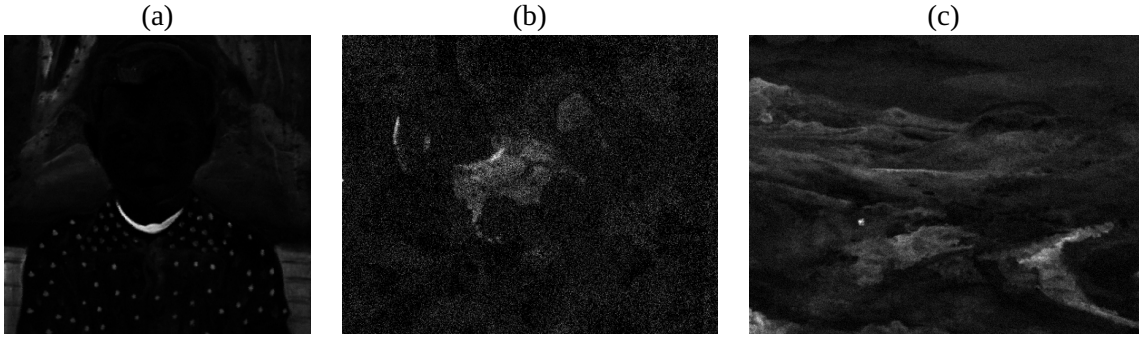
(a) (b) (c)



In all of these paintings, Figures 8(a)-(c), iron appears associated with brown-toned materials. In the case of the painting *Paisagem de Sabará*, iron also appears associated with a green tone, while in *Natureza Morta*, it is associated with regions of red tone. In the painting *Menino*, the black hair also appears associated with the elemental map of iron.

The elemental map of cobalt (Co) also appears in all three artworks, as illustrated in Figure 9.

Figure 9 - The cobalt (Co–Kα and Kβ) map was observed in regions of the three paintings, in the following sequence: (a) *Menino*, (b) *Natureza Morta*, and (c) *Paisagem de Sabará*.



This element Co is commonly associated with the pigments cobalt blue ($CoAl_2O_4$) and cobalt green ($CoO \cdot nZnO$).

In all of these canvases, Figures 9(a) and 9(b), the elemental map of cobalt was observed in association with blue tones — for example, in the painting *Menino*, in the blue dots of the clothes; in *Natureza Morta*, in the blue-toned cloths; and in *Paisagem de Sabará*, in the waters of the river. This indicates a repeating pattern in the use of cobalt-based blue pigments across the three canvases. In the painting *Paisagem de Sabará*, the elemental map of cobalt also appears in regions of green tones.

Comparative analysis with Guignard research data

Although the artworks used as a standard, Figures 2(a) and 2(b), are from a different period than the painting in question, the results also show compatibility with pigments detected in paintings from other periods, as indicated by the *Guignard Survey* (Moresi & Neves, 2012), which includes the works *Murilo Mendes (1930)*, *São Sebastião (1935)*, *Cecília Meireles (1940)*, and *Vera Chaves (1943)* — one of which dates from the same year as the painting *Menino* (1935). Table 1 shows the chemical element compatibilities found between the painting in question and those studied during the *Guignard Survey* (Moresi & Neves, 2012).

Table 1 - Compatibility of chemical elements found in the questioned work, *Menino* (1935), and in the works studied in *Guignard Research* (Moresi & Neves, 2012).

Work	Year	Ba	Ca	Zn	Pb	Cr	Fe	Co
Menino	1935	*	*	*	*	*	*	*
Murilo Mendes	1930	*		*	*			*
São Sebastião	1935		*	*				
Cecília Meireles	1940	*	*	*	*		*	
Vera Chaves	1943	*		*	*	*		*

From “Pesquisa Guignard”, by C.M.D. Moresi, and A.R.A Neves, 2012, UFMG.

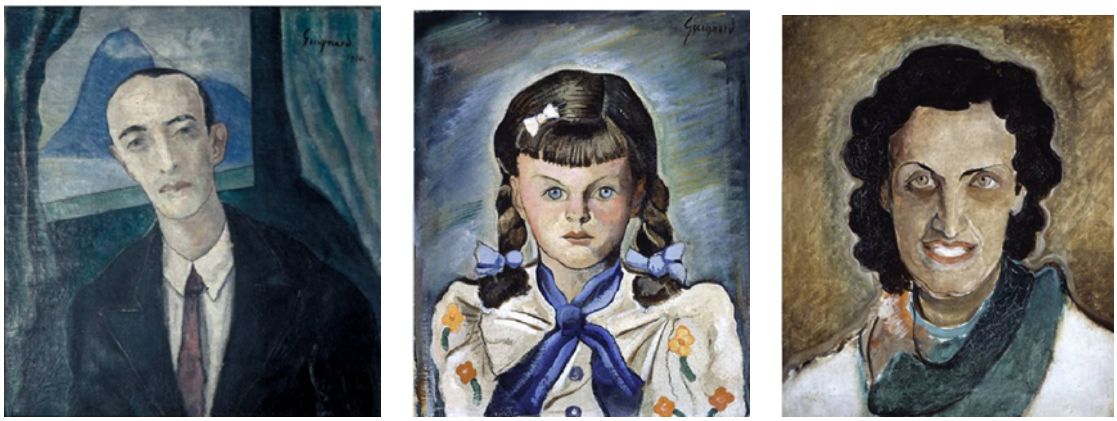
Materials with barium, calcium, zinc, and lead can be used in the imprimatura or as filler for paints, with materials associated with these elements commonly being barium sulfate ($BaSO_4$), calcium carbonate ($CaCO_3$), zinc white (ZnO), and lead white ($(PbCO_3)_2 \cdot Pb(OH)_2$). The presence of calcium sulfate was ruled out due to the absence of sulfur in the analyses.

The elements chromium and cobalt appear in the *Guignard Research* (Moresi & Neves, 2012) in association with the green and blue pigments present in the clothes of the characters in the paintings *Murilo Mendes* (1930) and *Vera Chaves* (1943), Figures 10(a) and 10(b), in an approach similar to that found in the questioned

work *Menino* (1935). Similarly, the element iron appears in the *Guignard Research* (Moresi & Neves, 2012) in association with the black pigment in the hair of the character in the painting *Retrato de Cecília Meireles* (1940), Figure 10(c), in a similar manner to what is found in the questioned work *Menino* (1935).

Figure 10 - Artwork produced by the author Guignard, using the oil on canvas technique: (a) *Retrato de Murilo Mendes*, 60 cm ×52 cm, (1930), (b) *Retrato de Vera Chaves*, 46 cm x 38cm, (1943), and (c) *Retrato de Cecília Meireles*, 46 cm ×38 cm, (1940).

(a) (b) (c)



Conclusions

The forensic analysis of a painting is a transdisciplinary work involving different fields of knowledge, such as financial, artistic, historical, biographical, graphotechnical, and physicochemical examinations. Given the approaches of studies to be carried out, the physicochemical investigation stands out, as it makes it possible to obtain numerical data that can be reproduced and compared objectively.

The results obtained in this study demonstrated the potential of the MA-XRF technique as a valuable tool in the resolution of forensic cases. In the real case at hand, the data acquired through this method provided important insights into the creation processes and materials, which were crucial for the authentication of the painting *Menino*, created by Guignard in 1935.

By comparing the data recorded from the questioned painting with those obtained from the standard paintings examined and the data provided in the *Guignard Research*, it is possible to identify several similarities in the creation process and materials of the paintings. The results also indicate that the artist likely maintained similar habits in his creative process over time. These similarities are most evident in portraits of known individuals.

By determining the authenticity of the artwork, the flagrant crime could be recorded, as the criminals were being sought for the theft of the authentic work, perpetrated through false imprisonment and bodily harm. If there were doubts regarding authenticity, the arrest in the act would not have been carried out.

Author contributions

N. T. Rocha Junior contributed to: conceptualization, data curation, formal analysis, investigation, methodology, projects management, resources, supervision, visualization, writing – original draft. **C. R. F. de Souza** contributed to: conceptualization, data curation, formal analysis, investigation, methodology, projects management, resources. **V. de S. Felix** and **A. R. Pimenta** contributed to: conceptualization, data curation, formal analysis, investigation, methodology, projects management, resources, supervision, programs, validation. **R. P. de Freitas** contributed to: conceptualization, data curation, formal analysis, investigation, methodology, projects management, resources, supervision, programs, validation, visualization, writing – revision and editing.

Supplementary material

The supplementary material supporting this study is available at the following cloud storage link: Guignard_Supplementary_Material

Conflicts of interest

The authors certify that they have no commercial or associative interest that represents a conflict of interest in relation to the work reported in this article.

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