

Review

Physical Fit Analysis in Forensic Anthropology: Its Role in Fragment Reassociation and Human Identification

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Abstract

Physical fit analysis has become an important complementary approach in forensic anthropology, particularly in cases involving fragmented human remains, where fragment reassociation is often critical to human identification. This review examines the role of physical fit analysis in fragment reassociation and its contribution to identification in forensic contexts, including disaster victim identification. To this end, the available literature was critically reviewed, with emphasis on physical fit, fracture matching, fracture morphology, and the interpretation of skeletal discontinuities in fragmented remains. The reviewed studies indicate that physical fit analysis can support the recognition of corresponding fragments, the reconstruction of disrupted skeletal regions, and the integration of anthropological findings with other identification methods, especially in cases involving highly fragmented or commingled remains. At the same time, the literature reveals important limitations, including methodological heterogeneity, limited validation studies, and interpretive challenges related to preservation and fracture complexity. Overall, physical fit analysis represents a promising adjunct in forensic anthropology for fragment reassociation and human identification, although further standardization and validation remain necessary to strengthen its forensic applicability.

Keywords: forensic anthropology; fracture pattern analysis; fragment reassociation; human identification; fragmented remains; disaster victim identification; fracture matching; physical fit



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1. Introduction

Fracture analysis was originally developed within materials science and engineering as a systematic approach to understanding how materials fail under specific loading conditions. In these disciplines, the examination of fracture initiation, propagation, and surface morphology became essential for interpreting failure mechanisms and relating them to the structural and mechanical properties of the material (Brooks et al., 2020; Roux et al., 2015; Thompson et al., 2024). Over time, these concepts were incorporated into forensic science, where they provided a more analytical framework for the interpretation of fractured evidence. Their application to skeletal remains was particularly significant in forensic anthropology and forensic medicine, as it encouraged a shift from purely descriptive

classifications of bone trauma toward an understanding of fracture as a mechanically conditioned process. In this context, bone fracture came to be interpreted not only as evidence of skeletal disruption, but also as a potentially informative feature for the analysis of trauma, fragment reassociation, and, ultimately, human identification (Kirbach et al., 2026; Weber et al., 2015, 2026).

Human identification remains one of the central objectives of forensic anthropology, particularly in cases involving fragmented, commingled, or otherwise incomplete human remains. In such contexts, the loss of anatomical continuity hinders the recognition of corresponding skeletal elements, delays the reconstruction of body regions, and complicates the application of conventional identification methods. These challenges become especially pronounced in contexts of commingling, incomplete recovery, and disaster victim identification (DVI), where highly fragmented remains, often from multiple individuals and recovered under adverse conditions, require a careful and multidisciplinary approach (Clavandier, 2023; De Boer et al., 2019; Hanson & Fenn, 2024; Moreira Araújo et al., 2022; World Trade Center Operational Statistics, 2019).

Within this context, fracture pattern analysis has emerged as a potentially valuable complementary tool in forensic anthropology and forensic medicine (Weber et al., 2021a). Beyond its traditional relevance to trauma interpretation, the analysis of fracture morphology also supports fragment reassociation by identifying correspondences between disrupted bone surfaces, evaluating physical fit, and recognizing structural continuity across fractured segments (Finlayson et al., 2017; Palmiotto et al., 2024). Under such circumstances, additional analytical approaches become necessary as physical fit analysis offers a relevant contribution by supporting the recognition of corresponding fragments through the assessment of margin compatibility and structural continuity, thereby assisting reassociation beyond gross anatomical observation alone (Bourgeois et al., 2021; Byrd & Adams, 2003).

The forensic relevance of fracture analysis in this setting lies in the understanding that fracture formation is a mechanically conditioned event influenced by the structural properties of bone, the direction and magnitude of loading, and the circumstances of force application. Consequently, fractured surfaces retain morphological features that assist in assessing whether separated fragments were originally part of the same skeletal element or anatomical region. In fragmented remains, this possibility has direct implications for reconstruction, reassociation, and ultimately human identification (Dirkmaat, 2015; L'Abbé et al., 2019; Passalacqua & Rainwater, 2015).

Although fracture pattern analysis has been widely discussed in relation to skeletal trauma and fracture biomechanics, its specific role in fragment reassociation and human identification remains comparatively less synthesized in the forensic anthropology literature (Christensen et al., 2018, 2022). Discussions on the subject are often dispersed across studies on trauma interpretation, fracture mechanics, fracture matching, physical fit, and case-based forensic applications, with limited integration of these perspectives into a focused review of their relevance to identification practice (Bourgeois et al., 2021; Dirkmaat, 2015; Finlayson et al., 2017; L'Abbé et al., 2019; Passalacqua & Rainwater, 2015; Weber et al., 2021b).

Accordingly, this review examines the role of fragment reassociation and its contribution to human identification in forensic anthropology. Attention is given to fragmented and commingled remains, including DVI contexts, as well as to the practical and interpretive limitations that affect its forensic application.

2. Materials and Methods

This study was conducted as a focused review of the literature on physical fit analysis, fracture pattern analysis, fragment reassociation, and human identification in forensic anthropology and related forensic contexts. Relevant publications were identified through

searches in PubMed, Scopus, and Web of Science. The search covered studies published between 2000 and May 2026 in order to include both foundational and recent contributions relevant to the topic. Search terms included “fracture pattern analysis”, “fracture matching”, “physical fit”, “fragment reassociation”, “forensic anthropology”, “human identification”, “fragmented remains”, “commingled remains”, and “disaster victim identification”. These terms were used in different combinations across the databases to maximize retrieval of relevant studies. Studies were included when they addressed the forensic application of physical fit, fracture correspondence, or fragment reassociation in human remains, particularly in the context of skeletal reconstruction and identification. Publications focused exclusively on non-forensic materials science, unrelated clinical or orthopedic contexts, or topics not directly relevant to fragment reassociation or human identification were excluded. Records were screened by title and abstract, and full texts were assessed when necessary. The primary source of study identification consisted of the database searches. As a supplementary step, the reference lists of eligible studies retrieved through the initial search were manually screened to identify additional relevant publications that had not been captured in the database search. The selected literature was analyzed qualitatively, meaning that the studies were assessed through a non-statistical interpretive review focused on their relevance to the aims of the manuscript. Priority was given to publications that contributed directly to conceptual clarification of physical fit and related approaches, forensic applications in fragment reassociation, relevance to human identification and DVI contexts, methodological discussion of validation and limitations, or practical interpretation of fragmented and commingled human remains.

3. Conceptual Clarification of Terms

The terms fracture pattern analysis, fracture matching, physical fit, and forensic fractography are related but not synonymous, and they are used here with distinct meanings. In this review, fracture pattern analysis is treated as the broadest concept, referring to the interpretation of fracture morphology and configuration in a forensic context, including their relevance to reassociation, reconstruction, and identification. Fracture matching refers more specifically to the comparison of separated fractured surfaces or skeletal segments to assess correspondence between fragments. Physical fit is used in an even narrower sense, referring to the direct refitting of fragments through morphological and structural continuity. Forensic fractography, in contrast, refers to the analysis of fracture surface features associated with fracture initiation, propagation, and arrest, with emphasis on failure mechanics rather than refitting itself. Although these approaches overlap in practice, they differ in scope and immediate purpose. For the purposes of this review, fracture pattern analysis is used as the broader interpretive framework, whereas fracture matching and physical fit are discussed as specific approaches to reassociation, and forensic fractography as a distinct analytical perspective on fracture surfaces.

4. Fracture Matching and Physical Fit in Forensic Anthropology

Fracture matching is of special importance in forensic anthropology, particularly when conventional anatomical criteria are insufficient to establish correspondence between separated skeletal segments. In fragmented remains, the examination of fracture morphology can help determine whether distinct bone fragments were originally part of the same element by assessing the compatibility of fractured surfaces, the continuity of structural features, and the overall coherence of the break pattern (B. J. Adams & Konigsberg, 2008).

One of the main principles underlying this approach is that fracture formation is a mechanically conditioned event rather than a random process. The initiation and propagation of a fracture are influenced by bone structure, loading direction, force magnitude, and the

circumstances of the traumatic event (Bourgeois et al., 2021). As a result, fractured surfaces may retain morphological characteristics that reflect the specific dynamics of failure. In forensic practice, these characteristics support the recognition of matching fragments when corresponding surfaces display compatible contours, complementary irregularities, and consistent structural alignment (Byrd & Adams, 2003).

This approach is closely related to the concept of physical fit, in which separate fragments are examined for direct morphological compatibility. Physical fit analysis involves the visual and manual assessment of complementary fractured or broken margins, the evaluation of cortical and trabecular continuity, and, in some cases, the reconstruction of disrupted skeletal regions through direct approximation of fragments (Bourgeois et al., 2021; Outram et al., 2005). When successful, such reassociation provides strong support for the interpretation that the fragments originated from the same skeletal element. In fragmented remains, this contribution is especially relevant when traditional anatomical landmarks are absent, incomplete, or insufficiently distinctive (Glencross, 2014).

Physical fit also extends beyond gross surface correspondence. The examiner may consider fracture trajectory, thickness relationships, curvature, internal architecture, and the spatial coherence of the disrupted region. In some cases, fracture morphology can help differentiate between fragments that are merely similar in size or shape and those that demonstrate true structural continuity. This distinction is particularly important in assemblages containing multiple fragmented elements, where erroneous reassociation leads to reconstruction errors and compromises the identification process (Bourgeois et al., 2021; Glencross, 2014; Palmiotto et al., 2024).

The forensic value of reassociation is especially evident in cases involving commingled or highly fragmented remains. In such contexts, the ability to identify corresponding fracture surfaces helps reconstruct body regions, reduce uncertainty in the sorting of skeletal material, and improve the anatomical organization required for subsequent identification procedures (B. J. Adams & Konigsberg, 2008). This is particularly relevant in DVI scenarios, where the integrity of victim reconstruction depends on the accurate grouping of fragmented remains before additional comparative methods are applied (Palmiotto et al., 2024).

Despite its usefulness, fracture matching should not be regarded as a self-sufficient or infallible method of reassociation. Its interpretation can be affected by postmortem damage, erosion of fracture surfaces, thermal alteration, missing intervening fragments, and observer-dependent judgment. For this reason, fracture matching is best understood as a complementary approach that could assist in reducing the number of DNA samples. Even so, when carefully applied, fracture matching offers important support for the reassociation of skeletal fragments and thereby contributes directly to forensic reconstruction and human identification (Malfroy Camine et al., 2022; Sarwar & Sarwar, 2026).

5. Physical Fit and Human Identification

In forensic anthropology, the reassociation of fragmented skeletal elements is not an end in itself, but a critical step toward human identification. The correct grouping of bone fragments restores anatomical continuity, permits more accurate reconstruction of body regions, and creates the structural basis required for the application of other identification methods. In this context, fracture pattern analysis contributes to identification by strengthening the evidentiary connection between separated fragments and supporting the reconstruction of remains at the individual level (Machado et al., 2022).

Physical fit testing should be performed with caution, as direct refitting alters fracture surface features relevant to later fractographic analysis. Fracture surfaces should therefore be documented and examined first, and physical reassociation should only be attempted after these features have been adequately recorded (Christensen et al., 2018, 2022).

Fragment reassociation also contribute to the distinction between fragments belonging to the same individual and fragments that are only superficially similar. In fragmented or commingled assemblages, this distinction is essential, since misassociation lead not only to reconstruction errors but also to serious identification inaccuracies. By supporting the recognition of true structural continuity between fractured segments, fracture matching help reduce ambiguity in the sorting and organization of skeletal material (Anastopoulou et al., 2021; L'Abbé et al., 2019).

In DVI and other mass fatality scenarios, this function becomes particularly important. The identification process often depends on the prior reassociation of body parts and skeletal fragments before the application of comparative methods such as odontology, medical, radiology, DNA analysis, or anthropological comparison. In this sense, fracture matching does not replace established identification techniques, but serve as a valuable adjunct by improving the anatomical coherence of the remains submitted for further examination. Its value lies in supporting the reconstruction of the individual as a biological and forensic unit (Clavandier, 2023; De Boer et al., 2019; Hanson & Fenn, 2024). Accordingly, the role of fracture-based approaches in identification is best understood as supportive, context-dependent, and intrinsically dependent on integration with other established forensic methods (Finlayson et al., 2017; Palmiotto et al., 2024).

6. Applications in Disaster Victim Identification

Disaster victim identification presents one of the most demanding operational settings for forensic anthropology, particularly when the event produces fragmented, commingled, burned, or otherwise extensively altered human remains (Araújo et al., 2022; Gunawardena et al., 2019; Malfroy Camine et al., 2022; Tettamanti et al., 2025). In these scenarios, the recovery process often yields incomplete and anatomically disconnected elements, requiring systematic procedures for sorting, reassociation, reconstruction, and eventual identification (Furtado et al., 2024; Monteiro et al., 2024). Under such conditions, fracture pattern analysis provide practical support by assisting in the recognition of corresponding skeletal fragments and by contributing to the reestablishment of anatomical continuity (Mundorff et al., 2025; World Trade Center Operational Statistics, 2019).

Its relevance in DVI derives from the fact that fragmentation frequently prevents the immediate application of conventional identification methods. Before odontological, medical, radiological, genetic, or anthropological comparisons can be fully effective, the recovered remains must first be organized in a manner that accurately reflects the individual body as much as possible (B. J. Adams & Konigsberg, 2008). Fragment reassociation is therefore a fundamental step in the DVI workflow, since errors at this stage affect the integrity of subsequent analyses, generate duplication of victims, or compromise the interpretation of traumatic findings (Malfroy Camine et al., 2022).

Within this context, physical fit aid in the reconstruction of fragmented skeletal regions by identifying compatible fracture surfaces, evaluating fracture matching, and supporting the association of segments that otherwise remain disconnected. This is particularly useful in assemblages involving multiple victims, where commingling and extensive disruption of remains increases the risk of erroneous grouping. By helping to distinguish true correspondence from superficial similarity, fracture matching reduce uncertainty during sorting and improve the anatomical consistency of reconstructed remains (Clavandier, 2023; Malfroy Camine et al., 2022).

Emblematic DVI cases demonstrate that extensive fragmentation is a recurrent, rather than exceptional, challenge in victim reassociation and human identification. In the World Trade Center disaster, 2753 victims died and, despite decades of advances in genetic analysis, only 1653 had been identified by August 2025, underscoring the long-term impact of

extreme fragmentation and commingling of remains (B. Adams et al., 2022; Biesecker et al., 2005; Warnasch, 2016; World Trade Center Operational Statistics, 2019). In the MH17 crash, all 298 occupants died and 296 were identified, illustrating the complexity of recovering and organizing human remains in high-impact aviation disasters (Kuipers et al., 2020; Vermeij et al., 2022). In the Brumadinho's Vale S.A. dam collapse, 603 biological materials were analyzed during the first-year identification effort, of which 86.2% corresponded to body parts and 13.8% to intact bodies; 259 of the first 270 victims were identified, highlighting the central role of fragment-based examination in mass fatality scenarios. Today, seven and a half years after the Vale S.A. disaster, 268 victims were identified (Moreira Araújo et al., 2022; Silva et al., 2024). Taken together, these events show that, in DVI contexts, accurate fragment reassociation can be a critical step in restoring the anatomical coherence of human remains and supporting reliable identification.

The practical relevance of fracture matching in a DVI situation is illustrated in Figure 1, in which the reassociation of fragmented skeletal elements of two different cases from the Vale S.A. dam disaster in Brumadinho was supported by the recognition of compatible fracture morphology and physical fit.

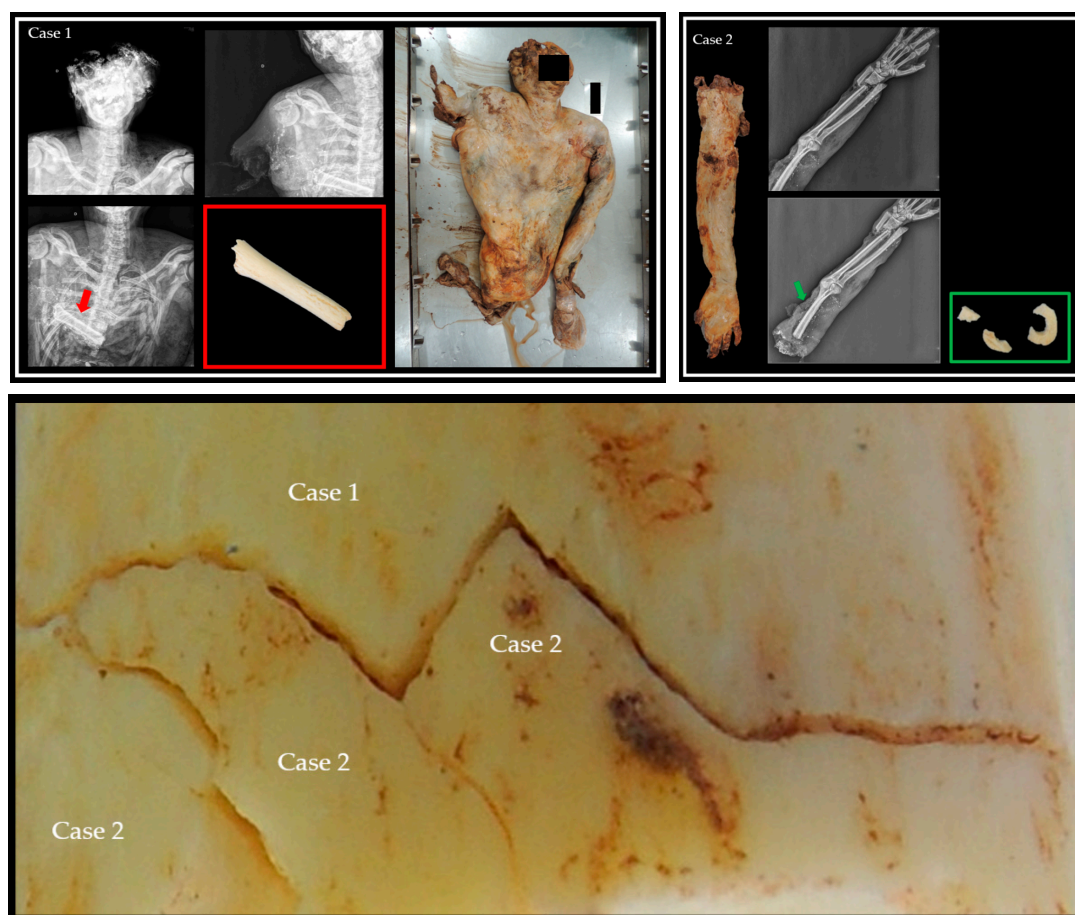


Figure 1. (Upper left) Case 1 on the autopsy table, consisting of incomplete human remains. Radiographic images showing the right humerus (red arrow) and the prepared right humerus (red box) are displayed adjacent to the remains. (Upper right) Case 2 on the autopsy table, consisting of an incomplete right upper limb. Radiographic images showing the right humerus (green arrow) and the residual portions of the right humerus following sectioning for DNA analysis are displayed adjacent to the specimen (green box). (Bottom) Physical refitting of the humeral fracture from Cases 1 and 2, demonstrating correspondence between the fracture surfaces and supporting the conclusion that both sets of remains originated from the same individual. Case 2 was identified by DNA analysis, whereas Case 1 was identified through physical fit with Case 2.

The value of this approach is not limited to technical reconstruction. In DVI operations, accurate reassociation has direct human and legal implications, as it supports the identification of victims, the proper return of remains to families, and the reliability of medico-legal documentation. In this sense, physical fit play an important auxiliary role within the broader multidisciplinary framework of disaster victim identification (Malfroy Camine et al., 2022).

Nevertheless, its application in DVI also faces important limitations. Fragment loss, thermal alteration, postmortem damage, contamination, and the presence of numerous incomplete elements can hinder the interpretation of fracture morphology and reduce the reliability of physical fit assessment. Moreover, the method remains dependent on examiner experience and on the condition of the recovered material. For these reasons, fracture matching in DVI should be applied cautiously and always in conjunction with other identification methods and established disaster protocols (Brooks et al., 2020; Gunawardena et al., 2019; Hanson & Fenn, 2024; Malfroy Camine et al., 2022).

7. Limitations and Evidentiary Caution

Although fragment reassociation offers important forensic contributions to human identification, its interpretation requires caution. Its value lies primarily in supporting the recognition of correspondence between fragmented skeletal elements, but this support is conditioned by the quality of preservation, the completeness of the recovered material, and the broader forensic context in which the analysis is performed. For this reason, physical fit should be understood as a complementary approach rather than as an isolated or self-sufficient method (Malfroy Camine et al., 2022; Outram et al., 2005; Silva et al., 2024).

One of the main limitations of this approach is the condition of the fracture surfaces themselves. Postmortem damage, weathering, erosion, thermal alteration, soil-related degradation, and handling during recovery or transport obscure or distort morphological features that would otherwise support fragment matching. In some cases, missing intervening fragments prevent the direct evaluation of continuity, making reassociation only partial or tentative. These factors substantially reduce the reliability of fracture-based interpretation, particularly in remains recovered from complex outdoor or mass fatality settings (De Boer et al., 2019; Gunawardena et al., 2019; Malfroy Camine et al., 2022; World Trade Center Operational Statistics, 2019).

Another important limitation concerns methodological heterogeneity and the limited strength of the available evidence. Much of the literature consists of case reports, descriptive discussions, or applied forensic examples, whereas comparatively few studies have systematically evaluated validation, reproducibility, or interobserver agreement. Standardized protocols for fracture-based reassociation remain scarce, and error-rate data are largely lacking. As a result, the interpretation of matching features often depends on examiner experience and qualitative judgment, introducing an observer-dependent component that affect consistency, reproducibility, and evidentiary weight. Accordingly, although fragment reassociation and physical fit have clear conceptual and practical relevance, their current forensic value is best understood as supportive and context-dependent rather than as a fully validated standalone approach (B. J. Adams & Konigsberg, 2008; Bourgeois et al., 2021; De Boer et al., 2020).

Physical fit also carries a risk of overinterpretation. Morphological similarity between fragments does not necessarily establish true correspondence, particularly when remains are highly fragmented or commingled. Superficial compatibility in contour, size, or shape misleads if not supported by broader structural coherence and contextual consistency. For this reason, apparent fracture matching should be assessed critically and,

whenever possible, in conjunction with other lines of forensic evidence (Finlayson et al., 2017; Thompson et al., 2024).

Malfroy Camine et al. (2022) critically noted that, despite the increasing use of virtual methods for the reassociation of fragmented human remains, no standardized protocol has yet been established for their integration into routine DVI practice. Their review underscores that current approaches remain methodologically heterogeneous and insufficiently validated, which limits reproducibility, operational consistency, and broader forensic implementation (Malfroy Camine et al., 2022).

A relevant advance in fracture comparison is the study by Thompson et al., who proposed a quantitative approach to matching forensic fragments using three-dimensional fracture surface topography and statistical learning. Their study, however, was performed on fractured metallic specimens rather than bone, which limits direct application to forensic anthropology. By combining 3D surface analysis with classification models, the authors assessed match versus non-match performance, addressed reproducibility through repeated imaging, and reported error-related measures, including false-positive and false-negative classifications. This is particularly important because it provides a structured framework for quantification and validation in fracture comparison (Thompson et al., 2024). Nevertheless, bone differs substantially from metal in its biological heterogeneity, anisotropy, and susceptibility to postmortem and taphonomic alteration. Therefore, although this study offers an important methodological reference, comparable validation studies on fractured human bone are still needed before similar conclusions regarding reproducibility, classification performance, and error rates can be supported in forensic anthropology.

From an evidentiary perspective, fracture-based reassociation is most appropriately viewed as a form of support rather than definitive evidence. Its forensic strength is enhanced when integrated with anatomical analysis, recovery context, radiological examination, and molecular or dental methods, depending on the case. In this multidisciplinary framework, fracture reassociation play a meaningful role in reconstruction and identification, but its conclusions should remain proportionate to the quality of the material and the degree of observed correspondence (American Academy of Forensic Sciences, 2021; Bourgeois et al., 2021).

The forensic and legal use of fracture-based reassociation also depends on broader considerations of standardization, validation, and evidentiary reliability. In legal contexts, the value of fracture matching and physical fit is not determined solely by their practical usefulness, but also by the extent to which the methods can be described transparently, applied consistently, and supported by reproducible criteria (Malfroy Camine et al., 2022). This is particularly important where reassociation findings may contribute to medico-legal conclusions or to the organization of remains submitted for formal identification (Bourgeois et al., 2021). In this respect, fracture-based reassociation currently functions more appropriately as supportive evidence than as a standalone basis for legal identification claims. Its evidentiary strength is greatest when interpreted cautiously and integrated with other forensic methods, including anatomical, radiological, odontological, genetic, and contextual analyses (Clavandier, 2023; Outram et al., 2005; Thompson et al., 2024). Accordingly, future progress in this area will require not only technical refinement, but also closer alignment with forensic standards and validation expectations relevant to scientific and legal scrutiny.

Despite their recognized forensic relevance, current reassociation methods remain limited by insufficient standardization, restricted validation, and substantial dependence on examiner interpretation. Brooks et al. (2020) highlighted methodological variability in physical fit comparison, whereas Malfroy Camine et al. (2022) noted the absence of standardized protocols for integrating virtual reassociation into routine DVI workflows

(Brooks et al., 2020; Malfroy Camine et al., 2022). Consistently, the AAFS/ASB Standard for Resolving Commingled Remains reinforces the need for transparent, structured, and reproducible procedures (American Academy of Forensic Sciences, 2021). Together, these observations indicate that reassociation methods remain promising, but not yet fully validated, forensic tools.

8. Future Directions

Future advances in fracture reassociation in forensic anthropology will depend largely on the development of more standardized and reproducible approaches to fragment reassociation. Although the current literature supports its practical relevance, particularly in fragmented remains and disaster victim identification contexts, the field still lacks broadly accepted methodological frameworks for describing, comparing, and interpreting fracture correspondence. Establishing clearer analytical criteria would strengthen consistency across practitioners and improve the evidentiary value of fracture-based reassociation (Osterholtz et al., 2014; Osterholtz, 2016; Palmiotto et al., 2024).

An important priority for future research is the validation of fracture matching methods under controlled and applied forensic conditions. Studies assessing interobserver agreement, reproducibility, and the reliability of reassociation criteria would be especially valuable, as investigations examining the influence of preservation, thermal alteration, weathering, and incomplete recovery on fracture interpretation. Such work is necessary to distinguish robust indicators of structural correspondence from features that misleads or overly dependent on subjective judgment (Baustian et al., 2014; Thompson et al., 2024).

Technological integration also represents a promising direction. Three-dimensional documentation, virtual reconstruction, imaging-based comparison, and digital modeling can expand the possibilities for fracture analysis, particularly when direct physical fit is limited or when fragile remains require non-destructive examination. These approaches can be especially useful in DVI settings, where large numbers of fragmented remains must be sorted and organized efficiently while preserving traceability and analytical rigor (Anastopoulou et al., 2021; Karell et al., 2016; Thompson et al., 2024).

Another important direction lies in the closer integration of physical fit with multidisciplinary identification workflows. Rather than being used in isolation, fracture-based reassociation should be increasingly examined in combination with radiological, medical, odontological, anthropological, and molecular methods. This integrated approach enhance the practical value of fracture analysis by situating it within the broader process of reconstruction and identification (Bourgeois et al., 2021; Finlayson et al., 2017).

Overall, future progress in this area will depend not only on technical refinement, but also on conceptual clarity regarding the forensic role of fracture pattern analysis. Its greatest potential lie in its use as a structured and well-contextualized adjunct to fragment reassociation and human identification, particularly in complex cases involving fragmented and commingled remains (Baustian et al., 2014; Osterholtz et al., 2014).

Emerging technologies are likely to play a central role in the future development of fragment reassociation in forensic anthropology. Three-dimensional modeling and virtual reconstruction already provide promising non-destructive alternatives for the comparison of fragmented skeletal elements, particularly in cases involving fragile remains, incomplete recovery, or complex commingling (Karell et al., 2016; Malfroy Camine et al., 2022). Quantitative surface comparison methods further expand this potential by allowing fracture correspondence to be assessed through measurable topographic features rather than solely through visual interpretation (Thompson et al., 2024). In parallel, automated and semi-automated matching systems may improve consistency and efficiency in large assemblages, while artificial intelligence and statistical learning approaches hold considerable promise

for pattern recognition, classification, and decision support in complex reassociation workflows (Anastopoulou et al., 2021; Baustian et al., 2014). Together, these technologies may enhance objectivity, reproducibility, and analytical precision, especially in DVI contexts, by reducing exclusive reliance on qualitative judgment. Their broader forensic incorporation, however, will depend on robust validation, transparent performance measures, reproducibility studies, and standardized protocols for routine practice.

9. Conclusions

Physical fit is a valuable adjunct in forensic anthropology and forensic medicine, particularly in cases involving fragmented human remains, where fragment reassociation can support human identification. The reviewed literature indicates that fracture morphology, fracture matching, and physical fit can assist in reconstruction and reassociation, especially in complex DVI contexts. However, their application remains limited by methodological heterogeneity, restricted validation, preservation-related challenges, and the risk of overinterpretation. Accordingly, fracture reassociation should be interpreted as supportive rather than definitive evidence and used in conjunction with other forensic methods. Further standardization and validation are needed to strengthen its applicability in human identification.

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Abbreviations

The following abbreviations are used in this manuscript:

IMLAR-BH	Instituto Médico Legal André Roquette-Belo Horizonte, Minas Gerais, Brazil
FCMMG	Faculdade Ciências Médicas de Minas Gerais, Brazil
UNICAMP	Piracicaba Dental School, State University of Campinas, São Paulo, Brazil

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