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FORENSIC MEDICAL ASPECTS OF BONE AND MUSCLE TISSUE FRAGMENTS

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Abstract: Bone and skeletal muscle tissue fragments are frequent objects of forensic medical examination in cases involving mechanical trauma, dismemberment, traffic injuries, explosions, fires, concealed remains, and advanced decomposition. Their evidentiary value is not limited to simple tissue identification. Macroscopic morphology, histology, imaging, immunohistochemistry, molecular methods, and postmortem biochemical changes may contribute to reconstruction of the mechanism and timing of injury, assessment of lesion vitality, identification of the deceased, and estimation of the postmortem interval. The aim of this review was to systematize the principal forensic-medical features of bone and skeletal muscle fragments and to define the strengths and limitations of their interpretation. A targeted narrative review of Uzbek forensic medicine textbooks and international peer-reviewed literature published mainly between 2009 and 2026 was undertaken. The reviewed evidence indicates that bone fragments are particularly informative for trauma-pattern analysis, biological profiling, DNA recovery, and distinction between traumatic and taphonomic defects, whereas muscle fragments are more responsive to early vital reactions and postmortem biochemical change. Reliable conclusions require integration of scene information, gross examination, histology and, when appropriate, radiology, immunohistochemistry, or molecular testing. No single tissue marker should be interpreted in isolation.

Keywords: forensic medicine; bone fragment; skeletal muscle; trauma; wound vitality; postmortem interval; histology; forensic pathology.

INTRODUCTION

Fragments of bone and skeletal muscle are common but sometimes underestimated sources of medico-legal information. They may be recovered from the body during autopsy, from surgical or traumatic wounds, or directly from a scene where a body has been fragmented by high-energy impact, sharp-force trauma, machinery, explosions, thermal exposure, animal activity, or deliberate dismemberment. In decomposed or incomplete remains, such fragments may represent the only tissues available for examination. Uzbek forensic medicine textbooks emphasize that every material object associated with trauma should be documented, preserved, and interpreted together with the circumstances of the case rather than as an isolated specimen (G‘iyosov, 2018; Iskandarov & Qo‘ldoshev, 2009; Indiaminov, 2020).

The forensic potential of bone and muscle differs because these tissues respond differently to mechanical force, healing, autolysis, decomposition, and environmental exposure. Bone retains

fracture morphology and tool marks for long periods and can therefore preserve evidence after soft tissues are destroyed. Skeletal muscle, by contrast, is biologically active and rapidly undergoes hemorrhagic, inflammatory, enzymatic, and protein-degradation changes; these features can be useful for assessing wound vitality and the early postmortem period. Contemporary forensic pathology therefore treats these tissues as complementary rather than competing sources of evidence (Pollak, Saukko, & Knight, 2026).

The central interpretive questions are usually whether a fragment is human, from which anatomical region it originated, whether observed damage is traumatic or postmortem, what type of force produced it, whether the injury occurred during life, and how much time may have elapsed between injury and death or between death and examination. These questions are clinically and legally important because overinterpretation may alter reconstruction of events, while underinterpretation may lead to loss of probative information. The present article reviews the major forensic-medical aspects of bone and skeletal muscle fragments with special attention to integrated morphological and laboratory assessment.

MATERIALS AND METHODS

A targeted narrative literature review was performed to synthesize practical forensic-medical approaches to the examination of bone and skeletal muscle tissue fragments. Sources were selected from core Uzbek-language forensic medicine textbooks and peer-reviewed international publications addressing skeletal trauma, wound vitality, postmortem tissue change, and skeletal muscle protein degradation. The reviewed period was centered on 2009–2026, while established forensic pathology principles from major reference texts were also included.

The material was organized according to five analytical domains: (1) recognition and documentation of tissue fragments; (2) interpretation of bone trauma; (3) assessment of muscle injury and lesion vitality; (4) postmortem and taphonomic change; and (5) evidentiary limitations. Only conclusions that can reasonably be applied to routine forensic practice were emphasized. Experimental or emerging biomarkers were described as adjunctive methods and not as stand-alone determinants. Because no individual case data were analyzed, ethical approval and informed consent were not applicable.

RESULTS

1. Forensic identification and documentation of fragments

Initial examination begins with preservation of chain of custody and detailed description of each fragment. For bone, the examiner records size, color, cortical thickness, trabecular architecture, anatomical landmarks, fracture surfaces, adherent soft tissue, burning, contamination, and possible tool marks. Radiography or computed tomography may help determine the anatomical origin and demonstrate fractures that are not evident macroscopically. Histological examination can confirm osseous tissue and identify remodeling or pathological change. When identification is uncertain, DNA analysis and species-specific molecular methods may be required. In fragmented remains, bone can also contribute to age, sex, stature, and individual identification, although the reliability of these estimates depends on the skeletal element available and the method used (G‘iyosov, 2018; Pollak et al., 2026).

Muscle fragments should be described by dimensions, color, consistency, visible hemorrhage, laceration pattern, relationship to fascia or tendon, contamination, and degree of decomposition. Sampling should include the injured zone and, whenever possible, an anatomically comparable

uninjured control. Formalin-fixed tissue is suitable for routine histology and immunohistochemistry, while fresh or frozen material may be necessary for protein, RNA, DNA, or biochemical analyses. The sampling plan must therefore be decided before all material is placed into fixative.

2. Interpretation of bone trauma

Bone fracture analysis is especially useful for differentiating blunt, sharp, firearm, and thermal injury. Blunt-force trauma can produce linear, radiating, depressed, wedge, spiral, or comminuted fractures depending on the anatomical region, direction, velocity, and area of force application. Sharp-force trauma may leave kerfs, notches, striations, false starts, or chop defects that can provide class-level information about the instrument. Firearm trauma can produce characteristic perforation, beveling, radiating fractures, and secondary fragmentation. These findings are most informative when interpreted as a pattern rather than from a single fracture line (Love & Wiersema, 2016).

A major difficulty is the distinction between perimortem trauma and postmortem breakage. Fresh bone contains collagen and moisture and tends to deform and fracture differently from dry or extensively decomposed bone. Nevertheless, color matching, fracture angle, surface roughness, and plastic deformation are not absolute indicators of vitality. Environmental weathering, burning, burial pressure, scavenging, recovery damage, and repeated handling can imitate traumatic defects. Reviews of skeletal trauma emphasize that fracture morphology is influenced by age, disease, cortical thickness, impact direction, and experimental conditions, so assigning a precise force magnitude from fracture appearance alone is generally not justified (Dempsey & Blau, 2020).

Histological evidence of hemorrhage, early inflammatory change, osteocyte alterations, vascular reaction, or initial repair may assist in establishing that a fracture occurred during life, especially when a survival interval existed. However, very early trauma may leave little or no microscopic healing response. Cappella and Cattaneo (2019) stressed that perimortem bone trauma occupies an interpretive gray zone because early vital signs may be subtle and taphonomic effects may obscure them. For this reason, the terms antemortem, perimortem, and postmortem should be used with clearly stated criteria and limitations.

3. Muscle injury, wound vitality, and wound-age estimation

Skeletal muscle is useful for evaluating whether a traumatic lesion occurred during life because living tissue can demonstrate hemorrhage, edema, contraction injury, inflammatory cell recruitment, and subsequent repair. Conventional histology may reveal interstitial bleeding, disrupted or hypercontracted fibers, neutrophilic infiltration, macrophage activity, and later regenerative changes. Yet hemorrhage by itself is not conclusive, because postmortem manipulation, resuscitation, gravity, and vascular disruption may also produce blood displacement. Therefore, lesion vitality should be based on a constellation of findings rather than a single microscopic feature (Li, Du, Bai, & Sun, 2020).

Immunohistochemistry and molecular biology can increase sensitivity by detecting inflammatory mediators, adhesion molecules, enzymes, cytokines, messenger RNA, microRNA, or other markers that change after injury. A systematic review by Maiese et al. (2022) concluded that histology alone is insufficient to prove vitality and that multimodal assessment provides the most defensible interpretation. Nevertheless, many candidate biomarkers remain affected by sampling site, survival time, disease, temperature, and analytical protocol. Their strongest role is therefore supportive, especially in cases where morphology is equivocal.

4. Postmortem change and estimation of the postmortem interval

After death, skeletal muscle undergoes predictable but highly variable biochemical and structural degradation. Proteolysis affects cytoskeletal and contractile proteins, and postmortem muscle excitability declines as cellular energy stores are exhausted. Recent reviews identify proteins such as desmin, alpha-actinin, vinculin, tubulin, tropomyosin, and related markers as promising research targets for postmortem interval estimation. However, temperature, body habitus, disease, muscle type, storage conditions, and laboratory technique substantially influence degradation profiles. Kori et al. (2026) therefore concluded that no single muscle protein is sufficiently reliable for stand-alone postmortem interval estimation.

Bone usually changes more slowly but is strongly affected by taphonomic processes. Surface bleaching, cracking, soil staining, root etching, thermal alteration, animal gnawing, mineral deposition, and post-recovery breakage may complicate the interpretation of trauma. Burned bone is particularly difficult because heat can cause shrinkage, color change, warping, delamination, and fractures that may resemble traumatic damage. The distinction between trauma and heat-related fracture is improved when fracture morphology is correlated with the surrounding scene, soft-tissue condition, and imaging findings rather than judged from color or shape alone.

Table 1. Main forensic value of bone and skeletal muscle tissue fragments

Object	Most informative features	Main limitations
Bone fragment	Fracture pattern; tool marks; ballistic defects; anatomical origin; remodeling; DNA; thermal and taphonomic change.	Perimortem vs postmortem overlap; age/disease effects; burning and weathering may modify fracture morphology.
Skeletal muscle fragment	Hemorrhage; fiber disruption; inflammatory response; immunohistochemical markers; molecular markers; protein degradation.	Rapid autolysis; temperature dependence; resuscitation artifacts; marker variability; need for control tissue and standardized sampling.
Combined assessment	Correlation of hard- and soft-tissue injury, scene findings, imaging, histology, and laboratory tests.	Interpretation becomes unreliable when fragments are examined without anatomical or scene context.

5. Evidentiary integration and laboratory workflow

The evidentiary value of a fragment depends not only on its morphology but also on how it is recovered and preserved. Each specimen should be photographed with scale, labeled by anatomical or scene location, packaged to minimize cross-contamination, and linked to a documented chain of custody. Bone fragments with possible cut, saw, or ballistic marks should not be cleaned aggressively before specialist examination because washing or scraping may alter microscopic surface detail. When DNA analysis is expected, a clean portion of the specimen should be protected from unnecessary handling. Muscle specimens require more rapid preservation: representative material for routine histology can be placed in buffered formalin, whereas separate unfixed samples should be frozen when protein or nucleic-acid analyses are contemplated. These principles are

consistent with the general evidence-preservation requirements described in Uzbek forensic medicine practice (G‘iyosov, 2018; Iskandarov & Qo‘ldoshev, 2009).

Laboratory examination should follow a stepwise question-driven sequence. Gross morphology and photography usually come first, followed by radiology or computed tomography when fracture geometry or foreign material must be clarified. Histology is then directed to the fracture edge, marrow, or muscle lesion margin. Immunohistochemistry and molecular testing are best reserved for defined questions such as lesion vitality or postmortem change, because their interpretation depends on validated controls and pre-analytical conditions. Destructive testing should be postponed until non-destructive observations are completed. A written expert opinion should distinguish findings that are directly demonstrated from conclusions that are probabilistic, and it should explicitly state when decomposition, heat, fragmentation, or limited sampling reduces diagnostic certainty (Maiese et al., 2022; Kori et al., 2026).

DISCUSSION

The principal finding of this review is that bone and muscle fragments provide different time-depths of forensic information. Bone is mechanically and environmentally durable, so it is especially useful when the body is fragmented, burned, decomposed, or skeletonized. Muscle is less durable but may preserve early biological responses that are important for determining lesion vitality and short postmortem changes. Combining the two tissues can therefore improve reconstruction. For example, a fracture pattern may suggest blunt impact while adjacent muscle hemorrhage and inflammatory changes support antemortem occurrence. Conversely, a fresh-appearing fracture without corresponding soft-tissue reaction must be interpreted cautiously, particularly after resuscitation, burning, or decomposition.

A second important point is that forensic interpretation should distinguish observation from inference. Describing a smooth-edged defect, cortical radiating fracture, muscle hemorrhage, or inflammatory infiltrate is an observation. Concluding that a specific weapon, exact impact force, or exact injury time produced the finding is an inference requiring additional support. This distinction is essential because experimental studies show substantial variability in skeletal response to blunt force, and wound-vitality literature demonstrates overlap between biological and postmortem changes. The same caution is reflected in Uzbek forensic medicine teaching, where expert conclusions are expected to be based on the full complex of case materials and laboratory findings (G‘iyosov, 2018; Indiaminov, 2020).

Sampling strategy is another determinant of reliability. In bone injury, the examiner should preserve the fracture margins before destructive sectioning and document them photographically and radiologically. Histological sections should include the fracture edge and adjacent intact cortex or marrow where appropriate. In muscle injury, samples should be taken from the lesion margin rather than only from grossly destroyed tissue, because the transition zone may contain more informative vital reactions. A control sample from unaffected muscle can help interpret nonspecific staining or postmortem change. If molecular testing is anticipated, unfixed frozen tissue should be preserved separately because formalin may limit some assays.

Emerging molecular approaches are promising but should not replace morphology. Wound vitality research increasingly uses panels of inflammatory or molecular markers, while postmortem interval research examines muscle protein degradation and supravital responses. These methods may eventually improve temporal precision, but present evidence supports a probabilistic rather than absolute interpretation. The most defensible report should state what the tissue findings

support, what alternative explanations remain possible, and which conclusions cannot be made reliably. Such calibrated reporting is more scientifically appropriate than assigning exact wound age or postmortem interval from a single histological or biochemical change.

This review has limitations. It is a targeted narrative synthesis rather than a systematic review with formal meta-analysis, and it combines textbooks with review articles from different methodological traditions. Some laboratory techniques have been studied primarily in experimental models rather than large human case series. In addition, local forensic protocols and laboratory availability vary. These limitations do not reduce the practical value of the combined approach, but they reinforce the need for standardized sampling, method validation, and correlation with case circumstances.

CONCLUSION

Bone and skeletal muscle tissue fragments are valuable objects of forensic medical examination because they preserve complementary information about identity, trauma, vitality, and postmortem change. Bone fragments are most useful for anatomical identification, fracture-pattern analysis, tool-mark assessment, DNA recovery, and evaluation of thermal or taphonomic effects. Skeletal muscle fragments are particularly informative for hemorrhagic and inflammatory reactions, wound vitality, and emerging biochemical approaches to postmortem interval estimation. However, neither tissue permits reliable stand-alone determination of exact injury time, exact force, or exact postmortem interval. The strongest forensic conclusions are obtained through an integrated workflow combining scene information, gross documentation, imaging, histology, and selectively applied immunohistochemical or molecular methods. Standardized sampling and cautious, evidence-weighted interpretation should remain the basis of expert practice.

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