



Anthropological analysis of trauma in throat bone and cartilage: A review



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ABSTRACT

In their analysis of recovered human remains, forensic anthropologists encounter structures of the throat (hyoid bone, thyroid cartilage/bone, cricoid cartilage/bone) that may present evidence of trauma. The recent published literature provides guidelines for the detection and interpretation of fractures in these tissues. Such traumatic injury frequently is associated with victims of hanging and strangulation, but many other causes have been recognized. Although the hyoid is not always recovered in skeletonized remains, it can reveal evidence of perimortem trauma and must be interpreted appropriately.

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1. Introduction

In 1992, the first author published a literature review focusing on the association of strangulation with hyoid fracture [1]. This effort was stimulated by a forensic case involving recovered remains of a child and suspected trauma. The hyoid had been recovered but displayed no evidence of trauma. As the trial on this case approached, investigators inquired about the probability of detecting trauma to the hyoid bone if manual strangulation had taken place. The literature review at that time suggested that if manual strangulation had occurred, it was unlikely to produce hyoid fracture since due to the young age of the decedent the greater horns (cornua) of the hyoid had not united to the body. The literature suggested that although in general hyoid fracture was most common in manual strangulations (about 34% of all cases), it is rare in children.

Since the 1992 review, a vast literature has emerged on the impact of throat trauma on structures of the throat [2,3]. This article reviews key aspects of that literature presenting the diverse types of neck trauma that can fracture the hyoid, thyroid, and cricoid and impact related tissues. Emphasis is placed on research published since the 1992 review article cited above.

2. The structures

The primary throat structures affected by trauma are (in descending anatomical order) the hyoid bone and thyroid and cricoid cartilage. Note however, that varying degrees of ossification of the thyroid and cricoid cartilage can occur. Although there is some debate about the embryologic development of the hyoid [4,5], most recognize considerable age variation in the union of its anatomical components. Throat structures demonstrate some anatomical variation that must be considered in evaluation [6]. A small triticeous cartilage structure also can occur [7].

The hyoid bone consists of a central body, small lesser horns (cornua) and larger greater horns (cornua). This horseshoe shaped bone does not articulate to any other bone but connects with the styloid processes of the temporal through the stylohyoid ligaments [1]. The three components of the hyoid each ossify from two centers. Ossification begins during fetal development, but union of the components is highly variable. Fusion of the greater horn to the body is more common in males than females [8], but rare prior to 20 years of age. Fusion of the greater horn sometimes can be unilateral, especially in females [8]. Adults display a general age progression of fusion [9] but with great variation [10,11]. Morphology of the adult hyoid also is highly variable [12] and related to body weight [13]. Hyoid morphology displays sex differences [14,15] and

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age-related changes [16]. Variation can include bilateral absence of the lesser cornua and abnormal morphology of the body [17].

Thyroid cartilage presents large superior extensions (cornua) and smaller inferior extensions. Ossification of hyaline cartilage can occur slowly [18,19] with great variation [20,21], has been detected as early as 14 years [22] and rarely, can lead to complete ossification [23,24]. Golghate et al. [25] report ossified thyroid cartilage in a 25 to 30-year-old male. Although some ossification of thyroid cartilage can occur, the patterns are too irregular to be useful in age estimation [26]. Thyroid cartilage measurements exhibit sex differences [27,28] and an association with living stature [29,30]. Anatomical variation can include unilateral and bilateral agenesis of the upper thyroid horns [31,32]. Morphometric research has revealed significant age changes in adults [33]. Thyroid cartilage can undergo significant age changes in flexibility [34] and histological structure [35] as well.

The ring-like cricoid cartilage is much smaller and thicker than the thyroid. Anatomical structure includes a posterior quadrate lamina and an anterior arch. Rare calcification of cricoid cartilage has been detected as young as seven years [36]. For more details on the development and anatomical structure of these tissues, consult Ubelaker [1] and Pinto [2].

Anatomical variation of these throat structures [37–39] and unusual patterns of ossification can complicate interpretation [40]. Some variations can be mistaken for trauma-induced alterations [41] or other medical issues [42]. For example, working in Singapore, Ng et al. [43] found that unusual cricoid ridge ossification, visible in plain radiography, can mimic ingested fish bone. Yagci et al. [44] described a complete stylohyoid soft tissue ossification in a patient from Turkey. Skrzat et al. [45] reported bilateral ossification of the stylohyoid ligament in a museum specimen from Poland. Ramadan et al. [46] described diffuse stylohyoid chain ossification in a patient from Turkey. Myositis ossificans traumatica can lead to ossification of the masticatory muscles [47]. Hilali et al. [48] described a patient with extremely large greater horns of the hyoid that were in contact with the third cervical vertebra.

3. Trauma detection

Detection of traumatic evidence in the structures of the throat is relatively straightforward with skeletonized remains but requires radiography and/or other techniques in the living and in complete and decomposing bodies. In the medical examiner office setting, the usual approach to assess these structures involves simple gross examination, layered dissection and maceration. Details on procedures involved and difficulties encountered are available in publications by Ref. [49–52].

Routine radiography can detect the most obvious fractures. For better resolution of bone density patterns and improved fracture recognition, Pollanen et al. [53] recommended xeroradiography. This technique utilizes a photoreceptor plate that is exposed to X-rays followed by application of a blue powder.

In medico-legal investigation, Khokhlov [54] noted that palpation and radiography can provide useful, preliminary information but complete preparation using a stereomicroscope was the method of choice. Khokhlov's retrospective study of 137 hanging cases revealed that stereomicroscopic investigation was much more successful in detecting injuries and avoiding false diagnosis.

Kempton et al. [55] noted the importance of multislice computed tomography (MSCT) in detecting fractures in strangulation cases. MSCT more successfully located fractures of throat structures than conventional autopsy. However, autopsy fared better in revealing soft-tissue injuries, especially hemorrhage. Kettner et al. [56] added that microfocus computed tomography (mfCT) offered more detailed information facilitating detection of thin fracture lines.

Baier et al. [57] discuss the use of micro-computed tomography in strangulation cases.

Microscopic examination of throat structures can reveal information regarding the timing of trauma [58]. Davison and Williams [59] presented a forensic case of a female homicide victim with a history of domestic violence. Microscopic analysis revealed a recent fracture of the larynx but also a fracture of the hyoid with evidence of remodeling. The larynx fracture supported the interpretation that strangulation was involved in her death. The hyoid with evidence of healing offered credence to an allegation that she had survived a previous strangulation attempt.

Although the published literature devotes considerable attention to the importance of structural bone and cartilage fracture in cases involving throat trauma, evidence of hemorrhage in associated soft tissue can be diagnostic [60]. As noted by Betz and Eisenmenger [61] detection of evidence of hemorrhage complements observations of structural fractures when soft tissue is available. In particular, muscle hemorrhages related to hangings concentrate at the origin of the sternocleidomastoid muscles and suggest the location of the ligature knot [62].

4. Clinical treatment

Although non-fatal fractures of throat structures, especially the hyoid, are rare they have been noted clinically [63–65]. Clinical symptoms of hyoid fracture include neck and throat pain, dysphagia (difficulty swallowing), odynophagia (painful swallowing), hemoptysis (airway bleeding), swelling and neck tenderness. Although such fractures usually are benign, some can lead to serious complications and even death [66]. The non-fatal injuries are similar to the fatal ones [67].

Ramchand et al. [68] noted that clinical management of hyoid bone fractures is highly variable. Treatment includes rest, diet changes, analgesia (pain relief), tracheotomy and other surgical procedures. Surgery is employed in only about 11% of cases. All forms of treatment produce positive results.

5. Causes

As noted above, throat trauma can result in fracture of the hyoid bone, and thyroid and cricoid cartilage and/or bone [69,70]. Of these three structures, the hyoid and thyroid are most commonly affected. Sharma et al. [71] studied deaths due to constriction of the neck, finding hyoid fracture in 21% of cases and thyroid cartilage fracture in 17%. Fracture was also more likely in individuals of advanced age, also noted by Clément et al. [72].

Green et al. [73] examined cases of suicidal hanging with respect to fracture of throat structures. They found that the highest incidence of fracture occurred with only thyroid cartilage (22.5%), followed by only the hyoid (10%) and both structures (15%). Lack of fusion or congenital absence of the greater horns in the hyoid were factors limiting fracture.

Zátoková et al. [74] published an autopsy-based study of deaths due to suicidal hanging. They found laryngo-hyoid fractures in 72.5% of the sample with fracture of the thyroid cartilage being most common (33.7%). Jayaprakash and Sreekumari [75] reported similar results (but with smaller values) in their study of autopsies following hanging (thyroid 5.3% and hyoid 2.7%). Thyroid cartilage fracture was associated with advancing age as well as the position of the ligature knot. In contrast, in an Istanbul study of 761 fatal suicidal hangings, Üzün et al. [76] found a higher frequency of fractures in the hyoid followed by the thyroid and then both structures.

Godin et al. [77] reported that fracture of the cricoid is rare in suicidal hangings but common in homicidal strangulation. In cases

of possible simulated hanging following homicidal strangulation [78], cricoid fracture may be a significant finding. Charoonnate et al. [79] found in Thai suicidal hangings, 25% presented fracture of the hyoid and thyroid. Knot location was not a factor, but age was associated. Regarding knot location in hangings, Nikolić et al. [80] found only a weak correlation with hyoid fracture but a stronger relationship with fracture of thyroid cartilage.

Most of the published literature focuses justifiably on fracture of throat structures resulting from hanging [81] and strangulation (manual and ligature) [82–84] but other forms of neck trauma can be involved as well. These include direct blunt force trauma to the anterior neck sustained in an automobile crash [85,86], gunshot injury [87], fist blows associated with fights [88] and incised wounds and explosions [89]. Bockholdt et al. [90] found that fractures of the upper thyroid horns can be produced by indirect whiplash and that the extent of ossification was a key factor. In such cases, the fracture location usually was found at the base of the horns. Experimental investigations suggested that a weight of 3 kg was required to produce thyroid horn fracture [90].

Neck trauma sustained in falls, even short distance, can produce laryngo-hyoid fractures [91,92]. Healed fractures of these structures have been detected in chronic alcoholics who experience frequent falls [93]. Jehng et al. [94] reported hyoid fracture produced by a fall from only 1.5 m.

Diverse other causes of throat structure fracture have been reported. Erdogan et al. [95] indicated that an isolated hyoid fracture resulted from an individual being struck with a metal rod during a fight. Hyoid fracture also has been produced due to excessive external laryngeal pressure during intubation or transoesophageal echocardiogram administration.

Sports injury has produced hyoid fracture. Chowdhury et al. [96] described a 16-year-old athlete who was struck in the neck by a hockey puck producing fracture of the body and right greater cornu. Multiple collegiate American football players have sustained similar injuries [97]. Porr et al. [98] reported traumatic hyoid fracture in a 13-year-old taekwondo athlete who was kicked in the anterior neck region.

Other forms of neck trauma resulting in hyoid fracture include induced vomiting [99,100], the helmet strap in motorcycle crashes [101,102], whiplash in crashes [90], and resuscitation [103]. Sustained microtrauma can produce alterations of thyroid cartilage. Age represents a key factor in all neck organ fractures [104].

Eckhardt et al. [105] reported healed fracture of the superior horn of thyroid cartilage resulting from autoerotic asphyxia. The investigating team employed three-dimensional surface scanning and printing, coupled with histologic analysis to detect the alteration.

Despite the variable factors cited above, manual strangulation associated with advanced age [106] represents the primary cause of hyoid fracture [107]. Hyoid trauma has been documented in strangulation survivors as well [108,109]. Although less common, hyoid fracture also can occur with hanging [110–112]. In a 1961 study of individuals with hyoid fractures, Weintraub [113] reported 50% associated with manual and ligature strangulation and only 27% with hanging.

Pollanen and Chiasson [114] found that the hyoid was more likely to fracture when fusion had occurred, and that shape of the bone also was a factor. In contrast, in their experimental study, Lebreton-Chakour et al. [115] found no difference between fused and non-fused bones in the tendency to fracture. However, hyoid fracture was less likely in individuals of general young age, slight build, with long hyoid length and with a small hyoid angle. Mukhopadhyay [116] agreed that hyoid size was a factor as measured using width, anterior-posterior length and greater coronal length. Pollanen et al. [53] found that the shape of the greater

cornu influenced the location of the fracture site. Fractures were most common in the posterior and middle thirds of the greater cornu and rare in the anterior third.

6. Anthropological casework

Discovery of significant trauma to bones of the throat represents an important component in the practice of forensic anthropology. For those anthropologists working in medical examiner offices such assessment is relatively routine. Their unique skills at structure recognition and interpretation are vitally needed in the analysis of remains that are extensively decomposed, burned, mummified or skeletonized. Decedents in these conditions with evidence of neck trauma are relatively common and represent a major component of the casework of anthropologists working within the medical examiner team.

Anthropologists working in other institutions primarily on submitted skeletal remains, may encounter evidence of neck trauma less frequently. In skeletonized cases, soft tissues, including cartilage, frequently are not available for analysis. In addition, the hyoid and any ossified components of the thyroid and cricoid are small and easily overlooked in the recovery operation, especially when anthropologists were not included in the recovery team. Proper interpretations of throat structure fractures and related trauma are especially important for those anthropologists who routinely participate in the analysis of cases involving suspected throat trauma.

7. Discussion

The recent published literature related to fracture of throat structures produced by trauma advances knowledge needed by forensic anthropologists in their routine casework. These publications reinforce long-standing awareness that interpretation must consider anatomical variation and delayed ossification and union of the structures involved. Detection of structure fracture continues to involve radiography and careful gross examination, but can be improved with enhanced xeroradiography, stereomicroscopic investigation and multislice computed tomography. Of course, with most cases that present soft tissues, layered dissection revealing neck structures can provide the necessary information. Once detected, structural fracture may reveal details needed to establish the timing of injury. Timing interpretation in forensic anthropology follows the traditional assessment of antemortem, perimortem and postmortem. Evidence of fracture healing/remodeling suggests antemortem injury and can establish a personal history of throat injury.

Cases involving throat trauma indicate that fractures of the hyoid and thyroid cartilage are most common. Cricoid fracture is rare in suicidal hangings but much more common in homicidal strangulation. Key factors leading to structure fracture induced by throat trauma include age, the extent of fusion of the hyoid anatomical components, the extent of ossification of the thyroid and cricoid, congenital absence of hyoid cornua and the size and shape of the hyoid. Although much of the literature focuses on throat trauma due to hanging and strangulation, many other causes have been documented as well. The great diversity of documented causes and influencing factors calls for caution in interpretation. Evidence of structure fracture must be considered in the total context of the case, including any possible soft tissue evidence.

The extent to which forensic anthropologists report on their interpretation of throat structures varies depending on the nature of their employment and types of cases submitted to them. For anthropologists working in the medical examiner office, such assessments have become relatively routine. For other

anthropologists who work in other environments, reports featuring discussion of neck structures are less common. Regardless of the nature of casework and place of employment, forensic anthropologists must be prepared to recognize and interpret properly these structures. The recent published literature provides perspective on the methods available and the complexities involved.

8. Conclusions

Forensic anthropologists are called upon to detect and analyze fractures of throat structures and must be aware of structural variation and the diverse factors that might be relevant. In skeletonized cases, these complexities begin with proper recovery of the hyoid and any surviving components of the thyroid and cricoid. If the relevant structures are recovered, advanced techniques of fracture detection may need to be employed. Analysis must focus on establishing the timing of any noted fractures and recognition of the diverse causes and factors that may be involved. Interpretation must be conservative and cognizant of the many factors that can mimic perimortem fracture. Although final case interpretation must rely on the total analysis and context, the forensic anthropology report may provide key information, especially related to timing and the nature of injury.

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Declaration of competing interest

The authors have no conflict of interest in this manuscript.

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