Rom J Leg Med [27] 221-229 [2019]
DOI: 10.4323/rjlm.2019.221

On the mechanics and topography of thyroid cartilage fractures

Klaus-Steffen Saternus[1], Reinhard B. Dettmeyer[2], Rainer Amberg[3], Christoph G. Birngruber[2,]*

Abstract: *Introduction.* For the evaluation of violent force to the neck, osseous injury patterns of the larynx play an important role. A thorough investigation of fracture patterns may allow reconstructive statements in autopsy cases as well as in clinical forensic cases.

Materials and methods. Preparatively (autopsy) and radiologically (x-ray images, equidensity images) documented cases of thyroid cartilage fractures were selected. Selection criteria were the diagnoses of ligature strangulation, manual strangling, lethal ligature/ manual strangling and shaped blunt force to the neck. The fracture patterns in the thyroid cartilage plates were related to the type of ossification and compared to theoretically expectable fracture patterns.

Results. Depending on the manner of force application and ossification, five different types of thyroid cartilage fracture patterns can be distinguished: type I is a paramedial sagittal longitudinal fracture resulting from a ventrally applied plane force (ligature strangulation); type II is a segmental fracture resulting from a medial point load (shaped blunt force); type III is a lateral sagittal longitudinal fracture from bilateral point load (manual strangulation); type IV is an intermediary segmental fracture resulting from central point load (manual strangulation); and type V is a break-out fracture of the inferior cornu resulting from lateral point load (manual strangulation). With combinations of ligature and manual strangling, corresponding fracture types can coincide.

Conclusions. Manual and ligature strangling can lead to distinguishable types of fracture in the thyroid cartilage. Thereby these types of fracture gain a diagnostic significance for the forensic-autoptical and clinical analysis of force to the neck.

Key Words: thyroid cartilage fracture, manual strangling, ligature strangling, classification, bio-mechanics.

INTRODUCTION

Generally, the dependence of fracture patterns on the direction and the intensity of a force is known. In the context of reproducibility, the term leading fracture is used. The question if a reproducible fracture pattern can be found under a defined vector in the complex topography of the larynx remained unanswered. This question was to be pursued for the types of force application of "plane ventral" (ligature strangulation), "point load ventral" (shaped blunt force) and "point load lateral" (manual strangulation) under consideration of the topography of ossification of the thyroid cartilage.

It is true that the most frequent fracture of the laryngeal bone frame is the fracture of the thyroid cartilage superior cornua [1-6], but fractures in the thyroid cartilage plates (TCP) resulting from violent force to the neck are not seldom. Among 179 cases of death due to ligature or manual strangling, they could be determined in 14% of the cases; among cases of mere ligature strangling in 4% and among cases of manual strangling in 15% [2]. These fractures are also common after indirect application of force. In an autoptical prospective investigation, they could be found in 5.6% (n=8) among 141 fatal jaw impact injuries caused by accidents [7].

In the present investigation, a typology of the

1) Institute of Legal Medicine, Kassel, Germany
2) Institute of Legal Medicine, Giessen, Germany
** Corresponding author: Justus-Liebig-University, Institute of Legal Medicine, Frankfurter Str. 58, 35392 Giessen, Tel.: +49 641 9941426, Fax: +49 641 9941419, E-mail: christoph.birngruber@forens.med.uni-giessen.de*
3) Forensic physician's office, Freiburg, Germany

fractures in thyroid cartilage plates (TCP) is proposed under the aspect of forensic injury reconstruction. The involvement of soft tissue and clinical aspects of a classification [8] will not be considered here. It has been pointed out correctly [9] that a large number of influential factors that are difficult to identify would have to be assumed for such a reconstruction. This is to be taken into account by a reduction of the number to only 3 variables. They are the topography of the thyroid cartilage fracture, the ossification pattern of the TCP and the type of force application. As in former investigations about the hyoid bone fracture [10,11], the type of force application is to be distinguished pragmatically, i.e. according to "plane medial" (ligature strangling), "point load medial" (shaped blunt force) and "point load lateral" (manual strangulation).

MATERIALS AND METHODS

The present investigation is qualitative research. For its purpose the collections of four university institutes of forensic medicine have been used. With knowledge of the origin of the injuries, manual and ligature strangling, a selection of preparatively and for the most part also radiologically documented specimens of larynx fracture were selected with the aim of producing an overall image of the thyroid cartilage fracture. A further larynx fracture was included that was the consequence of a compression with a tool (shoe). In addition to the diagnosis of the fracture, corresponding x-ray images also enabled an assessment of the spongy bone architecture of the thyroid cartilage plates. Their topography enabled a view of the material distribution and thus on the differences in the resistance of the thyroid cartilage plates. In close cooperation with Prof. Dr. Dr. h.c. Jürgen Koebke (†), Institute of Anatomy at the University of Cologne, equidensity images [6] were produced from selected x-ray images to obtain information about the material distribution.

For the analysis of the fracture, tensions in the thyroid cartilage plates were not measured but arranged qualitatively according to their type of force application to the exterior and interior surface. Thus, each pressure and tension side could be allocated correspondingly. The fracture patterns being theoretically expectable were related to real preparatively or radiologically diagnosed thyroid cartilage fractures with a known case history. The procedure of the analysis will be described in each case with the description of the fracture types (I-V) developed here.

The specimens (larynx and hyoid bones) stem from the current autoptical specimen collections of four institutes of forensic medicine, i.e. from the Universities of Cologne (1973-1984), the FU of Berlin (1985-1988), Göttingen (UMG) and Giessen (UKGM) as of 1989. Within the scope of court-ruled autopsies including the description of the soft tissue in the neck in so-called exsanguinity, they had been kept as evidence by order of the public prosecutor's office and prepared after completed formalin fixation. Until 1984, thyroid cartilage and hyoid bone had been x-rayed after preparation; as of 1985, before the preparation. As of 1985 specimens have been reprocessed using the Berlin Technique [12,13], in order to gain a direct view of the cartilaginous-osseous specimen.

RESULTS

The present investigation focuses on injuries of the bone frame of the thyroid cartilage as a result of a direct application of force. In no case could a thyroid cartilage fracture be found without an involvement of at least one of the two thyroid cartilage superior cornua. Exclusive subject of this investigation is to be the fracture of the thyroid cartilage plate (TCP). With a frontal application of force, the thyroid cartilage is strained mechanically in 3 different topographical regions, i.e. the front surface of the thyroid cartilage, the ring cartilage and the dorsal edge of the thyroid cartilage, the latter as contact area with the cervical spine (Fig. 1).

At which topographical height of larynx and hyoid bone the highest tensions can be found, depends also on the size of the surface through which the force is applied to the larynx; therefore, also from the width of the strangulation tool [7, 14]. Concretely, different types of fracture were the result; type I fracture (plane ventral application of force) and type II fracture (shaped ventral application of force). Here the type I fracture is the indirect consequence of the upward bending of the larynx on the abutment, i.e. the cervical spine. The fracture occurs when the force is distributed ventrally on a large surface.

In contrast, the type II fracture occurs directly at the point of force application. Then the medial segmental fracture in the TCP is the consequence of a

Figure 1. Plane compression of the larynx on the abutment of the cervical spine during ligature strangling. Spreading of the thyroid cartilage with highest tensions in the area of the commissure. Fracture of the left superior cornu of the thyroid cartilage (see also Fig. 5).

high local pressure tension under the point load and the counterforce distributed on the plane surface in the dorsum ossis thyroidei.

The direct ventral plane application of force (ligature strangling) and bilateral point load (manual strangling) often overlap. When investigating manual strangulation, a compression of the throat skeleton on the cervical spine must often be assumed as well. In a large population (n=99) with the leading diagnosis of ligature strangling, only 36% were ligature strangling processes [9] excluding other types of force applied. This corresponds with an investigation into 179 homicides of which a third of the cases showed combined manual and ligature strangling [2].

With the present fracture analysis, it was assumed as initial hypothesis that different forms of external violent impact also lead to different osseous damage. The centre of interest was always the distinction of pressure, tension and shear stress. For the purpose of orientation, tension and material distribution (ossification) in the TCP were related to each other for each of the suggested different types of fracture.

The present analysis showed that there are distinguishable basic patterns of thyroid cartilage fracture. It also showed that plane ventral and point load lateral force application can be distinguished by their corresponding thyroid cartilage fractures. Thus, for manual strangling as well as for ligature strangling, so-called leading fractures were determined. As a result five different fracture patterns of TCP could be distinguished, as shown in Table 1.

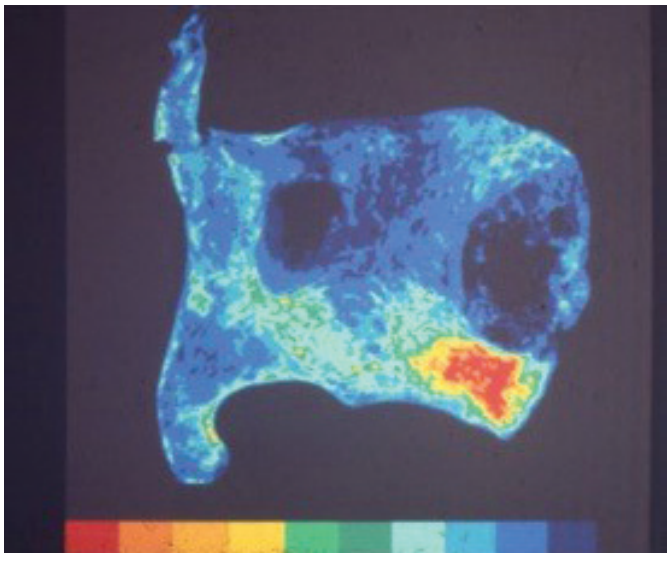

Figure 2. Semi-qualitative report of bone density (equidensities). Increase in density from blue to red. Typical male ossification mode as in the age group ≤ 4th decade. Strong dorso/caudal arc and ventro/caudal horizontal ring; cornu inferius slightly ossified. Fracture of the superior cornu. Ser.no. 419/73 K.

DISCUSSION

Type I – the paramedial fracture

According to its mechanics, the type I fracture of the thyroid cartilage can be explained by a frontal plane application of force. This means predominantly ligature strangling, hanging, blunt force but also agonal pressure. It has not been found in sports, as for example after stranglehold and headlock [15]. By plane application of force the throat skeleton is abutted against the cervical spine (abutment). As a result the larynx is spread open (Fig. 1). Simultaneously the tension from the rear edge of the thyroid cartilage to the commissure of the thyroid cartilage plates (TCP) increases. Under this load, the interior side of the TCP is the tension side, the exterior side is the pressure side. Whether it comes to a fracture and where it is located depends not only on the local tension but also on the resistance of the strained tissue.

For this reason, the spongy bone architecture, which has yet not been described much, is to be described in more detail in the following (Figs 2, 3).

In the German literature on anatomy, the terms "Incisura thyroidea superior" as well as "Incisura thyroidea inferior" (Iti) are used. This Iti is not mentioned in recent English or American anatomical atlases [16]. The preparations used in this investigation did not show any incisure either. On the contrary, the Iti was rather a flat arc with slightly ventrally bent-open, reinforced

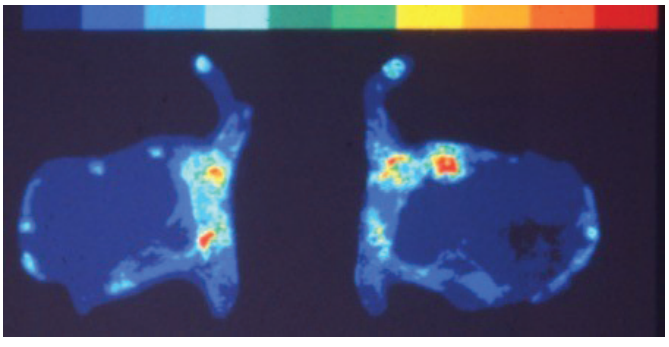

Figure 3. Equidensity image. Female ossification mode frequently in the age group ≤ 4th decade. Strong ossification of the dorsal edge of both thyroid cartilage plates, distinguishable ossification of the dorso/caudal arc, minimal ossification of the ventro/caudal arc and tender ossification of the commissure. Ser.no. 798/80 K.

Table 1. Classification of fracture types in thyroid cartilage plates (TCP)

Type of fracture	Configuration	Topography	Direction of fracture pattern	Illustration
Type I	sagittal	paramedial	longitudinal	4,5,6
Type II	horizontal	medial	segmental	7
Type III	sagittal	lateral	longitudinal	8
Type IV	central	intermediary	segmental	9
Type V	inferior cornu broken out	dorsal/caudal	arc-shaped	10,11

edges; especially as strong ossifications can be found relatively early in the larynx of males in the ventral part of the caudal thyroid cartilage edges (Fig. 2), so that there a continuous pressure-resistant arc has formed (Figs 2, 4). In such a constellation, a fracture would not be expectable in the medians. There the ossification of the lower edge of the TCP in the larynx of the female is significantly more tender (Fig. 3).

A sex dimorphism of TCP is known [17]. According to this research, the ventral half of the TCP was to remain unossified and unmineralised at the height of the insertion of the M. vocalis up to the 9th decennium. This statement is based on a radiological evaluation of 37 specimen. In the present material, the lack of ossification in the ventral area of the TCP can not be confirmed with such certainty (Fig. 3). Seen technically and independent of the ossification, protection against transverse displacement can be found also in the anterior commissure of both TCP of the female. In the depictions of prepared specimen of this investigation, the perichondrium/periost on the interior surface proved to be wide and strong in the median line, consisting of layers of collagenous fibre. It is a very narrow and taut synchondrosis. In the future, micro-CTs and 3D-reconstructions of the larynx are certain to produce significant information about it [18, 20]. In contrast to the Iti's themselves, the upper edge of the thyroid cartilage halves of the male up to an advanced age are also frequently irregularly ossified. For the question of the location of the fracture with plane application of force, the constellation is formed that the highest tensions are medial, i.e. in the area of synchondrosis, but that this region shows a higher resistance owing to its dimensions and ossification than its topographically neighbouring areas. Thus, the frontal thyroid cartilage fracture is not to be expected in the area of the commissure itself but in the varied neighbouring border layers of differing resistance (bone/cartilage borders, ossification gaps).

The theoretical expectation would be that this osseous/cartilaginous tear (tensile load) begins on the interior side of the TCP, namely paramedial. In the older anatomical writings [21], there is a reference to this but without indication of fracture mechanics: "In der Jugend verläuft die Bruchlinie regelmäßig neben der Mittellinie im höheren Alter genau in ihr." ("In youth, the fracture line runs regularly parallel to the median, in old age exactly on the median.") Our findings and experiences with homicides do not confirm such a dependence on age.

Figure 4 (ser.no. 275/86) shows the initial report as a consequence of death by ligature strangling of a 73-year-old woman. It is a right-sided lateral sagittal paramedial haemorrhage, namely perichondral with spreading to the cartilage (Fig. 4).

Maxeiner [22] shows the sequential stage of such an injury, namely a paramedial sagittal fracture exclusively limited to the interior side of a thyroid cartilage half. It was a condition after a multiple application of blunt force. He comments his analysis of 43 thyroid cartilage fractures that they were located predominantly at the frontal commissure, and that almost half of all the fractures did not fully penetrate the bone wall. The next consequential stage of indirect bending strain with ventral application of force shows the depiction of a larynx at two levels: the first is the cranial view (Fig. 1) and the second the ventral view (Fig. 5). As a consequence of the lateral bending and opening, the left TCP folded paramedially on its pressure side. For the tension side, i.e. the interior side, this can only mean an osseous rupture.

Three further paramedial sagittal fractures reported earlier from Cologne and Göttingen penetrated the TCP completely [23, 24]. One of the cases showed both types, type I and type II fracture [23].

As shown (Fig. 2), the anterior lower arc of the male is frequently very strongly ossified already as of the 4th decennium. Thus, the question arises how the paramedial fracture develops when reaching such ossification.

By means of a case history, a solution is to be provided. It is a larynx injury caused by hand edge impact, i.e. a short and hard impulse (Fig. 6). This led only to a ventral bursting of the thyroid cartilage but not to a significant abutment injury. Due to the high kinetic energy, the fracture line continued also to the anterior lower arc. However, it did not penetrate the strong ossified area directly, but continued at first dorsally along its upper edge. The fracture occurred only immediately before the tuberculum inferius. An explanation of this fracture pattern can be obtained from the equidensity image in Fig. 2. There the borders of the different osseous-cartilaginous density can be seen clearly. In the anterior arc, spongy bone bundles enter from the anterior and the posterior upper edge as well as some from the mid-level height of the dorsal edge. Before this unification, before the tuberculum inferius, inhomogeneities and intersecting spongy bone structures can be found in a slightly wider zone. Then, there is a place of relatively low bone density on which the fracture occurs.

In summary, the following criteria can be derived for the plane application of force: ventral plane force application leads to dorsal spreading of the larynx; then the highest tensions lie in the median line, i.e. in the commissure. The commissure remains intact due to its high form stability, correspondingly fractures occur paramedially in areas bordering on areas with significantly lower resistance. Theoretical assumption conforms with fracture morphology.

Hence, it is admissible to see the type I fracture as an entity of its own.

Type II – the medial horizontal fracture

In contrast to the plane application of force a point load can also lead to a medially localised fracture.

Fig. 7 shows such an example. It is a horizontal fracture of a 86-year-old woman caused by compression with a shoe. The pressure was applied to the larynx from the front right. A typical abutment injury was the fracture of the right thyroid cartilage superior cornu. The horizontal pattern of the fracture beginning medially can be explained firstly with the high local tension and secondly with the material distribution in the anterior area of the TCP.

The fracture lay in a bordering area between high and low resistance. Hence, the fracture did not occur incidentally. On the contrary, the anterior lower arc of the TCP formed the lower boundary. The impression ran caudally along this dense structure in a neighbouring cartilaginous area. For a male this would be a typical fracture pattern; with the female, especially the dorsal edge of the TCP ossified early and densely (Fig. 3), but

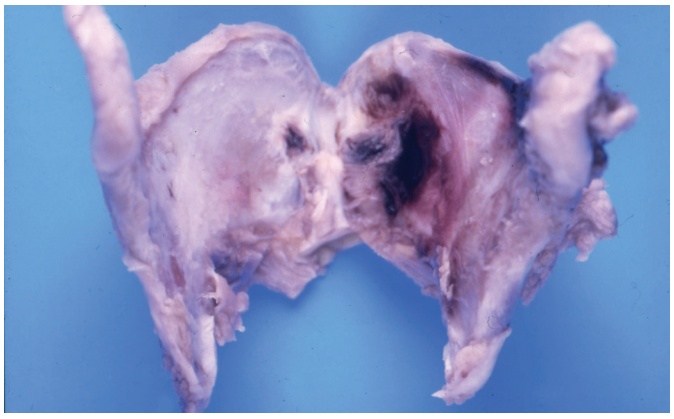

Figure 4. Lethal ligature strangulation. View of the interior side of the thyroid cartilage, on the right with subchondral and chondral haemorrhage. Fracture of right superior cornu. 73-year-old female.

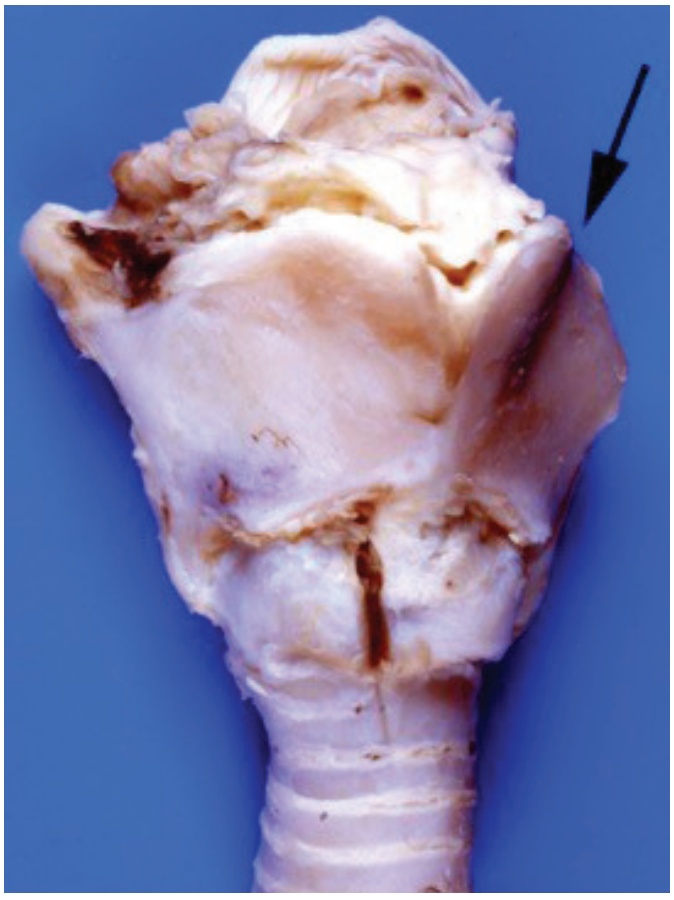

Figure 5. Frontal view of ligature strangulation (see also Fig. 1). Consequence of ventral compression maximum spreading of left thyroid cartilage plate to paramedial folding. Instability due to fracture of the ring cartilage and fracture of the left thyroid cartilage superior cornu.

Figure 6. Hand-edge impact applied to the front of the neck. Paramedial fracture of the thyroid cartilage frontal surface (ser. no. 241/78 K). With a short and hard impulse, the rear surface of the larynx including the thyroid cartilage cornua have remained intact.

Figure 7. Shaped neck compression (shoe). 86-year-old woman. Medial impression fracture. Fracture of superior cornu.

at an advanced age also the anterior lower arc more frequently.

Thus, with shaped ventral force application, there is a locus minoris resistentiae for the occurrence of a fracture in the anterior parts of the TCP. Insofar the shaped ventral impression fracture - type II - is a discrete type of fracture.

Type III – the lateral sagittal fracture

The thyroid cartilage plates show a high bone density in the dorsal edge of the thyroid cartilage plates (Fig. 2, 3). In addition there are also frequently significant mineralisations [17]. Correspondingly, in the radiological images a high gradient of different density (resistance) and - with knowledge of the structures - also elasticity can be seen clearly. This is relevant for the occurrence of the type III fracture (Fig. 8) as a consequence of the manual strangling effect. Thus cartilage with fine to cloddy mineralisation and/or fine spongy bone tracts (Figs 2, 3, 8) border to areas not ossified by the strong spongy bone bundles from the dorsal edge of the TCP. Shape and extension of the not ossified area vary throughout.

During manual strangling, pressure is applied with the thumb laterally onto the thyroid cartilage while the remaining four fingers form the abutment. In addition the larynx is pressed against the cervical spine, i.e. the immediate rear edge of the larynx is rigidly abutted. External pressure means tensile force on the interior side of the Lamina thyroida. Thereby, tears can occur in the actual dorsum itself between the spongy bone bundles. However, if the dorsal edge is densely ossified, the osseous tear will lie in the bordering area of bone/cartilage. Such a finding is shown in Fig. 8.

Even if Maxeiner [22] does not refer to the distribution of tension and pressure, the approach of this investigation can be based on his investigations, as he says that not only with ligature strangling but also with manual strangling the non-wall-penetrating fractures lie on the interior side of the TCP.

Among the material of this investigation, a medial parasagittal fracture (type I) in combination with a lateral parasagittal type III could be found with a 86-year-old woman after manual strangling (lateral point load). The report was already published earlier [23]. Such findings were not to be expected according to the findings on fracture mechanics developed here.

An explanation could be found with the equidensity image available. Thus, an extensive destruction of the caudal half of the TCP as well as a collapse of the complete thyroid cartilage occurred. The latter explains the medial parasagittal fracture encouraged by a low ossification of the TCP. Insofar this case history does not contradict the classification of the thyroid cartilage fracture proposed here. However, it shows the limits of its range of explanatory power.

In summary it can be said that the lateral parasagittal thyroid cartilage fracture (type III fracture) meets the criteria of a distinct entity. It is a reproducible fracture as a consequence of a defined application of force (lateral point load, i.e. manual strangling)

Type IV – the intermediary segmental fracture

In the practice of forensic medicine, a summative image of larynx injuries as a consequence of assault and multiple violent impact to the neck repeated at different times in the past is presented at least autoptically quite frequently. A typical example can be found in Ill.9 with callus formations on fractures of larynx and hyoid bone. Producing a chronological order of this is radiologically and histologically possible by examining the callus formation within the first four weeks after the event [25]. With a high recurrence of external insults over a longer period of time, even under consideration of the soft tissue, methods are stretched to their limits.

By means of plane blunt force combined with point load force application (ligature strangling, manual strangling/hitting) the TCP can be dismembered into fragments varying in size. A general assignment to ossifications and regressive changes of the cartilage, as well as in the spongy bone tracts developing with age in the bordering area of the anterior/intermediate third of the TCP (Figs 2, 7, 8) lead to unpredictable constellations for bursting or tearing phenomena.

The thyroid cartilage fracture type IV can neither be related to a unified form of force application nor to constant anatomical structures. However, the type IV fracture is no hotchpotch of different fractures including the other four defined type of fracture of the TCP. They can be derived and are reproducible.

Type V – break-out fracture of the inferior cornu

It also holds true for the break-out fracture of the inferior cornu (Fig. 10) that it occurs in a bordering area between higher and lower bone density. Very early and also with only little sex dimorphism, a strong and wide spongy bone bundle can be found that runs in the shape of an arc between the dorsal parts of the lower edge of the TCP and the lower edge of the posterior edge of the thyroid cartilage. Left out to a large extent is the narrow area of the TCP with the thyroid cartilage inferior cornua (Figs 2, 3, 9) located in dorso-caudal position to it.

In its bordering area the real fractures resulting from lateral point load force application (manual strangling) can be found (Figs 10, 11). The mode of fixation of the inferior cornua in the cricothyroid joint continues to be decisive for the fracture mechanics. As it is there that the medial excursions of the cornu inferius resulting from lateral force application to the TCP are limited by the coarse capsule with the ligg. articuli cricothyroidei. In addition, on the interior side there is a cricoid contact which has a splint-effect. However, if the cricoid itself fractures, then sufficient room arises for

the lateral shift. Then a tear-out fracture of the inferior cornu cannot occur anymore. Due to its ring formation the cricoid is quite pressure-resistant. With an intact cricoid, the inferior cornu is firmly secured caudally and elastically.

For this reason, the tear occurs between the only slightly ossified dorso/causal border area of the TCP and the cornu inferius and the solid osseous arc (spongy bone bundle). It is strictly speaking not a tear-out fracture of the cornu inferius with a more or less wide cuff but a tear-out fracture in the thyroid cartilage plate itself whereby the cornu inferius remains in place as a fragment. However, for the sake of vividness, it is justifiable to speak of a tear-out fracture.

If it comes to a further lateral shift of the larynx after the primary insult, the horn on the contralateral side of the fracture will bent outwardly by shearing. Correspondingly a fracture can occur. Such an example can be found in Figure 11: case of a 47-year-old women after manual strangulation.

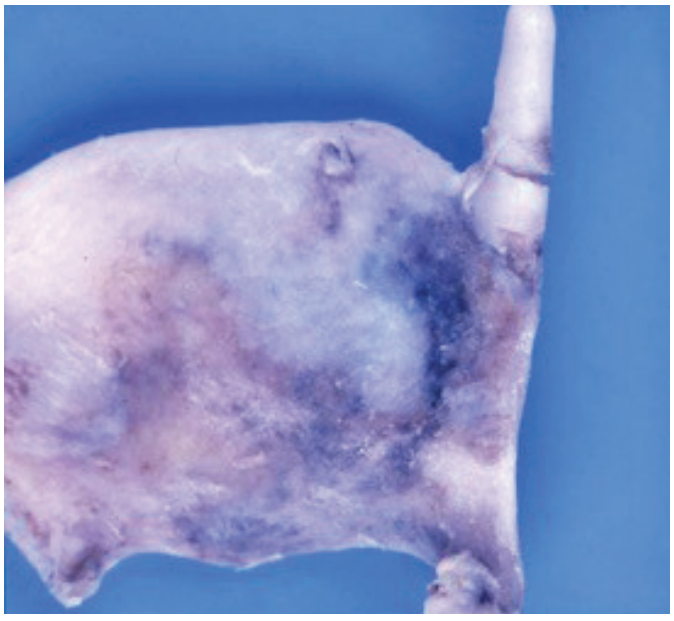

Figure 8. Manual strangling. Fracture running laterally parasagittally to the dorsal ossification area. View of the interior side of the lamina of the thyroid cartilage plate. Haemorrhage in the capsule of the cricothyroid joint. Fracture of the superior cornu. 30-year-old man. Ser.no. 156/85 B.

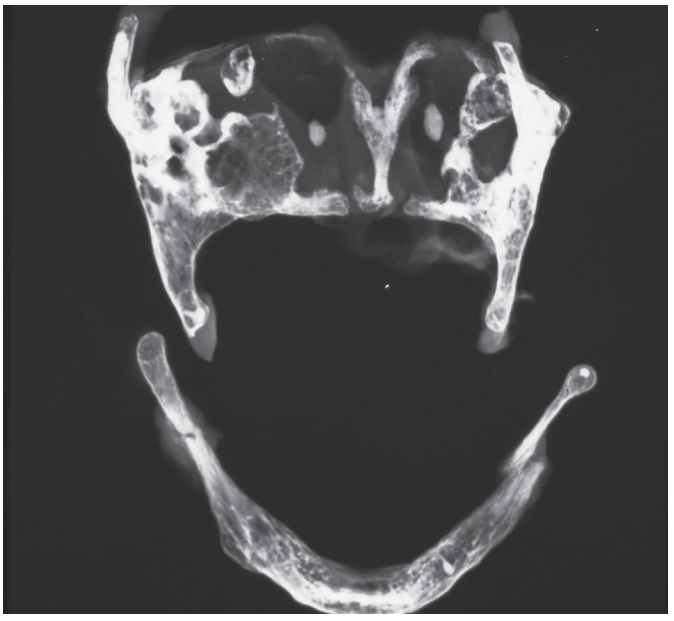

Figure 9. Many years of domestic violence. Older right-sided paramedial fracture of the thyroid cartilage as well as on both sides of the large hyoid bone cornu; callus in each case. Extensive ossification and mineralisation of the thyroid cartilage. 82-year-old woman.

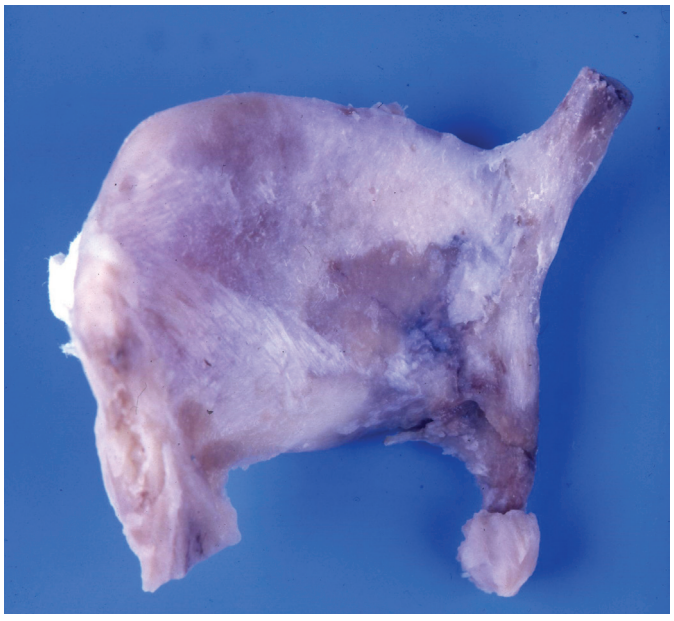

Figure 10. Manual strangulation. View from ventral, right thyroid cartilage plate. Tear-off fracture thyroid cartilage plate from cornu inferius. Type V fracture combined with lateral longitudinal fracture. Fracture of the superior cornu. 84-year-old woman.

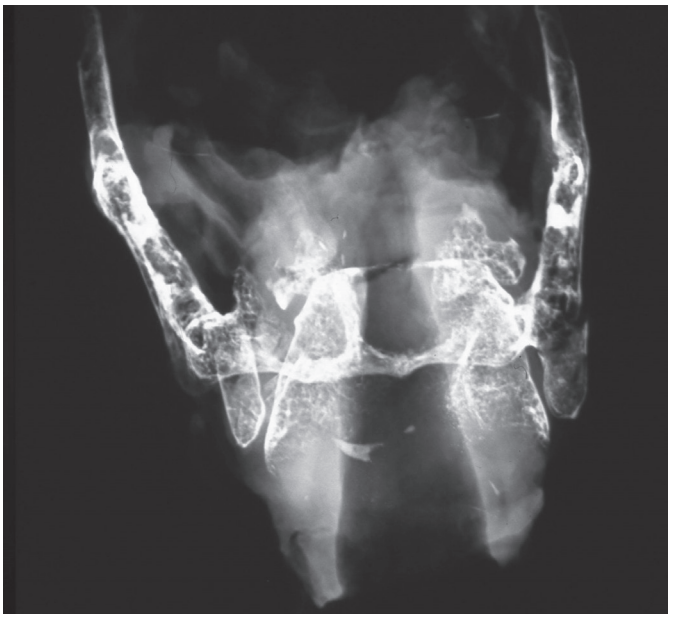

Figure 11. Manual strangulation. Tear-off fracture of thyroid cartilage plate on both sides of thyroid cartilage inferior cornu. Type V fracture. Massive haemorrhage and dislocation; to a large extent the left inferior cornu shows a position of the fragments that is true to the axis. 47-year-old woman.

The key to the extraction of the TCP from the cornu inferior is the mode of ossification. This is to be addressed again. In recent literature it is said that the ossification of the dorsal edge of the TCP begins at the egde of the inferior cornua or extends from there [26-29]. According to our investigation this is not the case. However, very early stages have not been included by this investigation. Our own earlier radiological examinations of 184 adult larynx specimens [23] as well as of a further 85 preparations [24] lead to the report proved by the equidensity images in Figures 2 and 3. As a rule, even in the senium with complete ossification of the thyroid cartilage, the dorso/caudal spongy bone bundle could be distinguished from the less ossified cornu inferius.

Firstly, fractures of the inferior cornua are considered unusual [2, 8, 30]; secondly, there is a singular opinion considering it the most frequent fracture of the larynx [31]. In our own forensic practice, they were common. The fracture mechanism has not yet been described. Figure 10 shows a break-out fracture of an inferior cornu with a 84-year-old women after death by manual strangulation. Fracture lines running from a centre ventro/cranially and parasagittally indicate the location of the point load application of force.

A comparable report of a 47-year-old woman is described in Figure 11. Here too, the cause of death was manual strangulation. The frontal surface of the larynx was intact. It was a application of force from the right. A lower ossification of the cornua inferior in comparison with the dorsum can be seen clearly on the otherwise not very informative a.p.-image. This image also includes information about the fracture mechanics. Whereas a translation of the TCP occurred under the point load from the right, the inferior cornua have remained in place.

Thus, the tear-out fracture of the thyroid cartilage from the inferior cornua ("inferior cornua tear-out fracture") is a well distinguishable fracture in the dorso/caudal parts of the thyroid cartilage plate. It is defined by a lateral point load (manual strangling) and a locus minoris resistentiae. Insofar the type-V-fracture is a distinct entity.

In conclusion, it can be said that it is possible to deduce the type of external violent impact by means of the fractures of thyroid cartilage plates. Even if the larynx with two large mutually connected osseous elements, thyroid cartilage and ring cartilage, is a mechanically complex structure, the spectrum of thyroid cartilage fractures is limited. Due to its close topographical neighbourhood of dense ossification to so-called permanent cartilage, but also due to the differences in density of the osseous structures with high gradients, vulnerable regions can be found in the thyroid cartilage plates. Depending on the type of external violent impact, fractures occur at these preformed locations with characteristic patterns. In order to serve as a general basis, 5 different types of fractures have been defined, namely type I, the paramedial sagittal fracture pattern with high resistance osteochondrosis in the border area to permanent cartilage; type II, the segmental fracture with defined lower limit in the area bordering at to the anterior/lower arc; type III, the lateral sagittal fracture at the dorsum ossis thyroideum in the border area to permanent cartilage; type IV, the multi-centric segmental fracture in border areas; as well as type V, the tear-out fracture in the dorso-caudal area of the thyroid cartilage plate of the thyroid cartilage inferior cornua fixated in the cricothyroid joints.

In all of the analysed fractures of the thyroid cartilage plates a fracture of the thyroid cartilage superior cornua could be found regularly at least once.

As outlook it can be said that the exact knowledge of the spongy bone architecture will be a key to fracture analysis. For this purpose and for the assessment of micro fractures in the spongy bone the deployment of micro-CT technology looks promising and corresponding investigation have been started in our work group [32, 33].

Conflict of interest. The authors declare that there is no conflict of interest.

References

1. Missliwetz J (1983) Verletzungen von Kehlkopf und Zungenbein beim Erwürgen und Erdrosseln. Arch Kriminol. 172: 29-31.
2. Maxeiner H (1990) Morphologische Befundmuster am Kehlkopf bei Strangulation. S.133-144. In: Brinkmann B, Püschel K (eds.) Ersticken. Springer, Berlin, Heidelberg, New York
3. Maxeiner H (1998) "Hidden" laryngeal injuries in homicidal strangulation: how to detect and interpret these findings. J Forens Sci. 43: 784-791.
4. Khokhlov VD (1999) Knitted fractures of the laryngopharynx framework as a medico-legal matter. Forensic Sci Int. 104: 147-162.
5. Rajs J, Thiblin (2000) Histologic appearance of fractured thyroid and surrounding tissue. Forens Sci Int. 114: 155-166.
6. Saternus KS, Maxeiner H, Kernbach-Wighton G, Koebke J (2013) Traumatology of the superior thyroid horns in suicidal hanging – An injury analysis. Leg Med (Tokyo). 15: 134-139.
7. Saternus KS (1979) Die Verletzungen von Halswirbelsäule und von Halsweichteilen. Hippokrates, Stuttgart
8. Kragha KO. Acute traumatic injury of the larynx. Case Rep Otolaryngol. 2015: 393978
9. Brinkmann B (2004) Ersticken. Pathophysiologie und Pathomorphologie des äußeren Erstickens. In: Brinkmann B, Madea B (eds.) Handbuch gerichtliche Medizin. Springer, Berlin, Heidelberg, New York, p. 709-720.
10. Koebke J, Saternus KS (1997) The adult human hyoid bone. Z Rechtsmed. 84: 7-18.
11. Saternus KS, Koebke J (1979) Fracture of the hyoid bone. Z Rechtsmed. 84: 19-35.

12. Maxeiner H, Dietz W (1986) Anleitung für eine vollständige Kehlkopfpräparation. Z Rechtsmed 96: 11-16.
13. Saternus KS (2007) Kehlkopf. In: Saternus KS, Madea B (eds.) Forensic autopsy. Handling of the human corpse. Schmidt-Römhild, Lübeck, p. 168-169.
14. Brinkmann B, Koops E, Wischhusen F, Kleiber M (1981) Halskompression und arterielle Obstruktion. Z Rechtsmed 78: 59-73.
15. Missliwetz J, Denk W (1990) Obstruktive Asphyxie in Kampfsportarten. In: Brinkmann B, Püschel K (eds.) Ersticken. Springer, Berlin, Heidelberg, New York, p. 35-41.
16. McHanwell, Stephen (2008) Larynx. In: Standring Susan (ed.) Gray´s Anatomy. The Anatomical Basis of Clinical Practice. Churchill Livingstone, London, 40th ed., p. 577-582.
17. Claassen H (1999) Untersuchungen zur Mineralisation und Knochenbildung im Schildknorpel und im ersten Rippenknorpel. Ein Beitrag zur Anatomie der sogenannten permanenten Knorpel. Shaker, Aachen
18. Kempter M, Ross S, Spendlove D, Flach PM, Preiss U, Thali MJ, Bollinger SA (2009) Post-mortem imaging of laryngohyoid fractures in strangulation incidents: first results. Leg Med (Tokyo) 11: 267-271.
19. Kettner M, Potente S, Schulz B, Knauff P, Schmidt PH, Ramsthaler F (2014) Analysis of laryngeal fractures in decomposed bodies using microfocus computed tomography (mfCT). Forensic Sci Med Pathol 10: 607-612.
20. Fais P, Giraudo C, Viero A, Miotto D, Bortolotti F, Tagliaro F, Montisci M, Cecchetto G (2016) Micro computed tomography features of laryngeal fractures in a case of fatal manual strangulation. Leg Med (Tokyo). 18: 85-89.
21. Merkel F (1899) Handbuch der topographischen Anatomie, Vol. 2. Vieweg und Sohn, Braunschweig, p. 55.
22. Maxeiner H (2004) Ersticken. Innere Halsbefunde. Verletzungen des Kehlkopfs. In: Brinkmann B, Madea B (eds.) Handbuch gerichtliche Medizin. Springer. Berlin, Heidelberg, New York, p. 734-748.
23. Scheik A (1987) Verletzungen von Zungenbein und Kehlkopf bei Tötung durch Erwürgen oder Erdrosseln, bei suizidalem Erhängen sowie bei Intubation. Inaug. Diss., Köln.
24. Thiel S (2005) Die dorsale Konfiguration des Schildknorpels. Inaug. Diss., Göttingen.
25. Dettmeyer RB (2011) Bone Fractures and Fracture Healing. Forensic Histopathology. Springer, Berlin, Heidelberg, p. 203-205.
26. Hunger H, Leopold D, Wunderlich G (1978) Röntgenologische Untersuchung zur Alters- und Geschlechtsbestimmung. In: Hunger H, Leopold G (eds.) Identifikation. Springer, Berlin, Heidelberg, New York, p. 248-258.
27. Leonhardt H (1987) Kehlkopf In: Leonhardt H, Tillmann B, Töndury G, Zilles K (eds.) Anatomie des Menschen. Vol. 2: Innere Organe. Thieme, Stuttgart, New York, p. 139-155.
28. Leopold D, Schäfer W (1998) Röntgenologische Methoden zur Identifikation. In: Leopold D (ed.) Identifikation unbekannter Toter. Interdisziplinäre Methodik, forensische Osteologie. Schmidt-Römhild, Lübeck, p. 289-325.
29. von Lanz T, Wachsmuth W (2004) Praktische Anatomie. Ein Lehr- und Hilfsbuch der anatomischen Grundlagen ärztlichen Handelns. 1. Band/ 2. Teil Hals. Schildknorpel. Springer, Sonderausgabe, Berlin, Göttingen, Heidelberg, p. 286-288.
30. Maxeiner H (2015) Strangulation. In: Madea B (ed.) Rechtsmedizin. Springer, Berlin, Heidelberg, p. 273-288.
31. Koriakina VA, Mishin ES (2015) The forensic medical characteristics and assessment of the neck injuries resulting from intubation. Sud Med Ekspert. 58 (2): 22-26.
32. Hartrampf LCM, Winzek CF, Kampschulte M, Pons-Kühnemann J, Saternus KS, Birngruber CG (2019) Zur Geschlechts- und Altersabhängigkeit der Ossifikation der Cartilago thyroidea. Eine forensisch-osteologische Analyse mittels Mikro-Computertomographie. Rechtsmedizin. 29: 101-109.
33. Winzek CF, Hartrampf LCM, Kampschulte M, Pons-Kühnemann J, Birngruber CG, Dettmeyer R, Saternus KS (2019) Unilateral and bilateral agenesis of the upper thyroid horns - A morphometric analysis of the larynx. Forensic Sci Int. 301: 225-230.