



**HAL**  
open science

## Biomechanical study of the thyroid cartilage: A model of bi-digital strangulation

C. Gagnon, S. Boismery, Y. Godio-Raboutet, L. Tuchtan, C. Bartoli, P. Adalian, K. Chaumoitre, M.-D. Piercecchi-Marti, L. Thollon

### ► To cite this version:

C. Gagnon, S. Boismery, Y. Godio-Raboutet, L. Tuchtan, C. Bartoli, et al.. Biomechanical study of the thyroid cartilage: A model of bi-digital strangulation. *Forensic Science International*, 2019, 302, pp.109891. 10.1016/j.forsciint.2019.109891 . hal-03570660

**HAL Id: hal-03570660**

**<https://hal.science/hal-03570660v1>**

Submitted on 23 Aug 2022

**HAL** is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



Distributed under a Creative Commons Attribution - NonCommercial 4.0 International License

## Biomechanical study of the thyroid cartilage: a model of bi-digital strangulation

C. Gagnon <sup>c\*</sup>; S. Boismery <sup>c</sup>; Y. Godio-Raboutet <sup>c</sup>; L. Tuchtan <sup>ab</sup>; C. Bartoli <sup>ab</sup>; P. Adalian <sup>a</sup>; K. Chaumoitre <sup>ad</sup>,  
M.D. Piercecchi-Marti <sup>ab</sup>; L. Thollon <sup>c</sup>

<sup>a</sup> Aix-Marseille Univ, CNRS, EFS, ADES, Faculté de médecine Secteur Nord, Marseille, France.

<sup>b</sup> APHM, CHU Timone, Service de Médecine Légale et Droit de la santé, Marseille, France.

<sup>c</sup> Aix Marseille Univ, IFSTTAR, LBA, UMR\_T 24, 13916 Marseille, France.

<sup>d</sup> APHM, Hôpital Nord, Service de radiologie, Marseille, France.

\*Corresponding author at Faculté de Médecine - Secteur Nord – Laboratoire de Biomécanique Appliquée,  
13916, Marseille

E-mail address: carogagnon06@me.com

S. Boismery : sophie.boismery@aol.fr

Y. Godio-Raboutet : yves.godio@ifsttar.fr

L. Tuchtan: Lucile.TUCHTAN@ap-hm.fr

C. Bartoli : Christophe.BARTOLI@ap-hm.fr

P. Adalian : pascal.adalian@univ-amu.fr

K. Chaumoitre: Kathia.CHAUMOITRE@ap-hm.fr

M.D. Piercecchi-Marti : Marie-dominique.PIERCECCHI@ap-hm.fr

L. Thollon : lionel.thollon@ifsttar.fr

**Abstract:**

The presence of fracture on neck elements is an indication of violence. Both the hyoid bone and the larynx can be damaged by a strangulation mechanism. Thyroid cartilage, more specifically, may present lesions in response to this mechanical stress. These lesions result in fractures at the bases of the horns of the thyroid cartilage.

This study focuses on the thyroid cartilage behavior in cases of bi-digital strangulation, using an anthropometric and biomechanical approach. To develop a biomechanical model, we performed an anthropometric study taking into account 14 distances measurements as well as 3 measurements of angles. These measures allowed us to determine a significant sexual dimorphism between individuals. Then, we define 6 morphologies models, composed of 3 females and 3 males individuals. In order to visualize the ossification of the cartilage, each model has been tested with bone properties. Strangulation cases were simulated by applying an imposed velocity of 0,4m/s then 1m/s. We observed different behaviors of the thyroid cartilage according to the sex and the morphology.

**Keys words:** Larynx, thyroid cartilage, strangulation, 3D modeling

## 1. Introduction

During autopsies, the neck is particularly observed in case of death by strangulation. The various elements of this anatomical region, the hyoid bone and the larynx, are indeed sensitive to fractures during this type of solicitation. Previous studies on the neck show a possible fracture of the hyoid bone [1,2], but also of the cartilage composing the larynx, in particular thyroid cartilage [3]. Nevertheless, this cartilage does not fracture in all cases [4–7], or lesions may not always be detectable [3,8]. Some morphologies may be more subjects at risk than others for a same level of pressure, for both the hyoid bone and the thyroid cartilage [1,9]. Furthermore, Plattner et al. (2005)[10] showed several levels of strangulation, which do not affect the cartilage. According to the authors, the rate of fractures during strangulation varies from 50% to 90% of trauma on the thyroid cartilage [11]. For strangulation the most common lesions are fractures at the bases of the horns.

The neck is a region that is fairly well protected, embedded between the jaw, chest and muscles. The larynx is more particularly a set of elements, cartilage, muscles and membranes, which protect the airway and vocal cords. It is mainly composed of thyroid, cricoid and arytenoid cartilage and epiglottis. In our study, we chose to mainly work on thyroid cartilage. This one is directly connected to the hyoid bone in its upper part and encases the cricoid cartilage in its lower part.

Its consist of a lamellar body with two quadrilateral laminae and four posterior horns (2 superior and 2 inferior) whose length can be very variable [11,12]. In addition, this cartilage changes over time, with slow ossification, beginning at the puberty and continuing throughout life [13–15].

This study aims at understanding the behavior of neck components during manual bi-digital strangulation and follows other studies developed by the Laboratoire de Biomécanique Appliquée on hyoid bone [1,2,16]. In order to visualize these behaviors, we have developed numerical models, varying the impactor velocity parameters and the morphology of the cartilage. The objective is to determine the possible variations of the required forces, necessary to fracture the thyroid cartilage, but also the types of fractures according to the evolution of the parameters.

## 2. Materials and methods

### 2.1. Materials

The data was collected from DICOM (Digital Imaging and Communications in Medicine) scanners, made at the Hôpital Nord of Marseille, as part of the diagnosis. The scanners were selected among the examinations carried out in the medical imaging department from January 2010 to May 2013 for

various indications. Only healthy individuals were selected, with no addiction that could have an impact on the larynx or a history of radiotherapy or calcium disorders. The sample is then composed of 78 individuals, 40 females (mean age  $52.43 \pm 19.15$ ) and 38 males (mean age  $49.71 \pm 18.14$ ). All the scans were anonymized.

## 2.2. Methods

### 2.2.1. Anthropometrics methods

The reconstructions of thyroid cartilage were performed using Mimics® v. 12.3 software (Materialize, Leuven, Belgium). The segmentation of the scans was semi-automatic. This software allowed us to perform anthropometric measurements to characterize the thyroid cartilage from a morphological approach. A total of 14 distances measurements and 3 angles measurements were made (Table 1) (fig 1).

1	Height of the lamellar body: from the center of the upper notch to lower part of the lamellar body
2	Height of left lamellar body: from the anterior point at the base of the upper left horn to the anterior point at the base of the lower left horn
3	Height of right lamellar body: from the anterior point at the base of the upper right horn, to the anterior point at the base of the lower right horn
4	Maximum length of the lamellar body: maximum width of the lamellar body from the lateral cartilaginous protuberances
5	Upper length of the lamellar body: upper width between the anterior point at the base of the upper horns
6	Lower length of the lamellar body: lower width between the anterior point at the base of the lower horns
7	Length of the lower right horn: from the lower center point to the anterior point of the lower right horn
8	Length of the lower left horn: from the lower center point to the anterior point of the lower left horn
9	Width of the upper horns: from the outer edge of the top of the upper horns
10	Width of the lower horns: from the outer edge of the top of the lower horns
11	Length of the upper left horn: from base to top
12	Length of the upper right horn: from base to top
13	Distance of the right horns: from the top of the upper right horn to the bottom of the lower right horn
14	Distance of the left horns from the top of the upper left horn to the bottom of the lower left horn
15	Angle of the upper horns: angle centered on the most central point of the upper central notch and for

	ends the top of the upper horns
16	Angle of the bases of the upper horns: angle centered on the most central point of the upper central notch and for ends the anterior point of the upper horns base
17	Angle of the bases of the lower horns: angle centered on the most central point of the lower central notch and for ends the anterior point of the lower horns base

Table 1: Anthropometric measurements of the thyroid cartilage

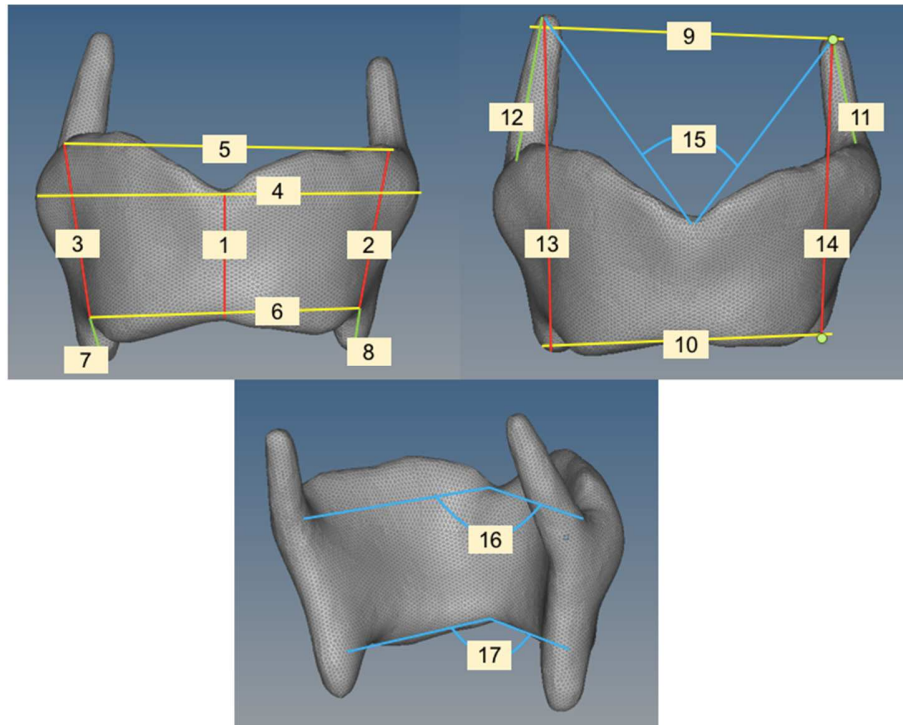


Figure 1: Anthropometric measurements

### 2.2.2. Statistical analysis

All the statistics were developed from R® 3.5.2.

Due to a significant difference between sexes for the thyroid cartilage [17], a descriptive analysis was performed. Boxplots were drawn for each measurement to determine observable differences between sexes. Then we tested the statistical significance of the results using a Student's test (T-test), with a significance threshold of 5%. This was to identify the difference in means of each measurement according to sex.

In addition, a Pearson correlation test was performed between anthropometric measures, sex and BMI. Once these correlations were estimated, we developed a decision tree to determine the combination of

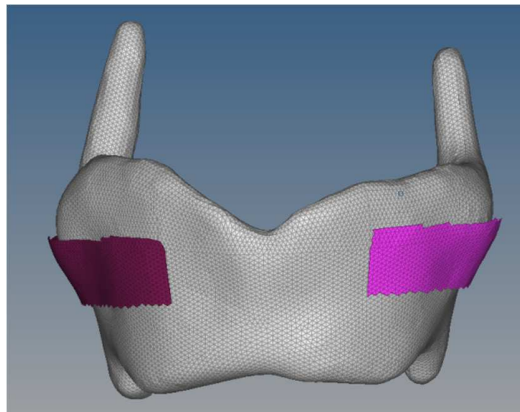
discriminant measures to classified individuals by sex. The decision tree error rate significance was tested from subsample of the studied population.

A PCA analysis was performed to determine different morphologies according to sex. Six biomechanical models have been developed, 3 males and 3 females. For each sex, the models represent a gracile, intermediate and robust individual. These models were selected according to the 10<sup>th</sup> centile, 50<sup>th</sup> centile and 90<sup>th</sup> centile, respectively.

### 2.2.3. Finite elements models

The first step concerned the 3D reconstruction of anatomical parts carried out with Mimics® software. The obtained surfaces were meshed in HyperMesh v12.0® (Altair, Troy Michigan, United States).

The impactors used in strangulation modeling were also defined using the HyperMesh v12.0® software. Two new surfaces were developed according to the curves of the thyroid cartilage. These surfaces were located at the lower part of the anterior medial notch of the cartilage (fig 2).



*Figure 2: Thyroid impactors (dark and light pink)*

The next step was to assign the various materials, properties, contact, initial and kinematic conditions to the models. For that, we used HyperCrash v12.0® (Altair, Troy Michigan, United States). In order to define the extreme characteristics of thyroid cartilage, we have chosen to assign bone properties to each model (3 females and 3 male models).

The mechanical properties used for the model, based on the literature, are summarized on the table 2.

	Materials	Density (g/mm <sup>3</sup> )	Young Modulus (MPa)	Poisson ratio	$\sigma_{Yield}$ (MPa)	Failure plastic strain (MPa)	$\sigma_{max}$ (MPa)	Thickness (mm)
Cortical bone	Elasto plastic/ Johnson Cook	0,002	3 000	0,499	90	0,04	100	1,25 (female) / 1,75 (male)
Cancellous bone	Elasto plastic / Ductile Damage 23	0,001	500	0,4	4	0,03	10	/
Impactor	Elastic/ Linear Elastic	0,0078	210 000	0,4	/	/	/	1

Table 2: Models properties

Cortical bone was represented by 2D elements and cancellous bone mesh by means of 3D elements. Both used an elastoplastic law. The thickness of the cortical part was set to 1,25mm for females and 1,75mm for males.

Then, for each model developed, boundary conditions were applied to the ends of the four horns to block all translations and allow all rotations.

For the impactors, 2D elements were associated with an elastic law. The thickness of these surfaces was fixed at 1mm. The two plates were defined as rigid body elements, only moving in translation on the axis perpendicular to the thyroid cartilage. An imposed velocity of 0,4m/s and then 1m/s was applied to simulate the strangulation movement.

Contact interfaces have also been used between the impactors and the cortical parts of the models.

### 3. Results

#### 3.1. Statistical results



Repeatability and reproducibility were tested for each anthropometric measurement. They respectively yield intraclass correlation coefficient of 0,992 and 0,977. Then the measures were analyzed according to the sex of the individuals.

### 3.1.1. Significant difference between measures

Student test indicated the average difference according to sex. The results show a significant mean difference ( $p\text{-value} < 0,05$ ) for all the measurement in this study.

The analysis of boxplots shows that the length measures are higher for males and the angle measures are higher for females. The boxplots illustrated the average difference for the lower length of the lamellar body (fig 3), and for the angle of the upper horns (fig 4).

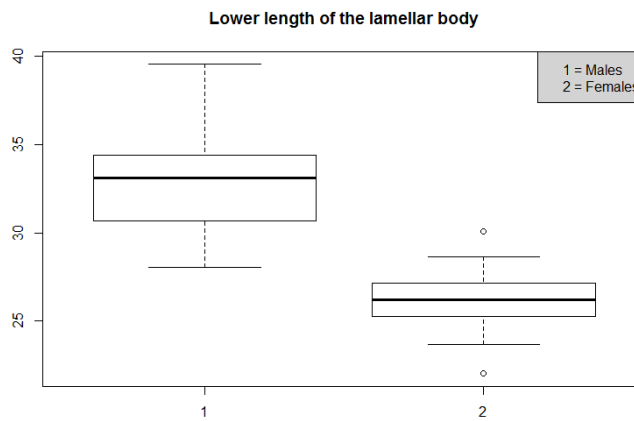


Figure 3: Lower length of the lamellar body

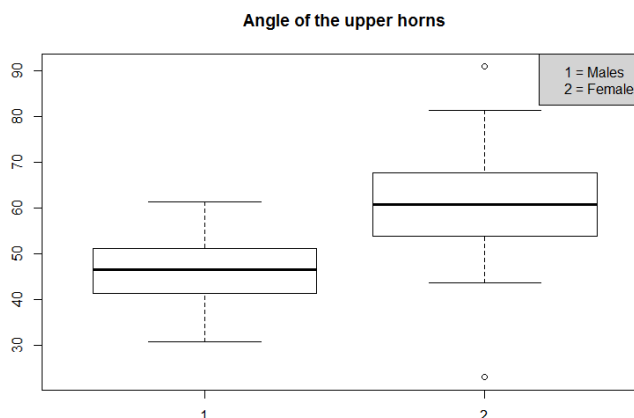


Figure 4: Angle of the upper horns

### 3.1.2. Correlation matrix

The correlation matrix shows several links between the measurements. The correlations were established and verified using significance test. Figure 5 shows the correlation and the p-value according to the measures. The strength of the correlation has a link with the circle darkness and correlation significance correspond to circle size. Red colors represent positive correlations and blue colors stand for negative ones.

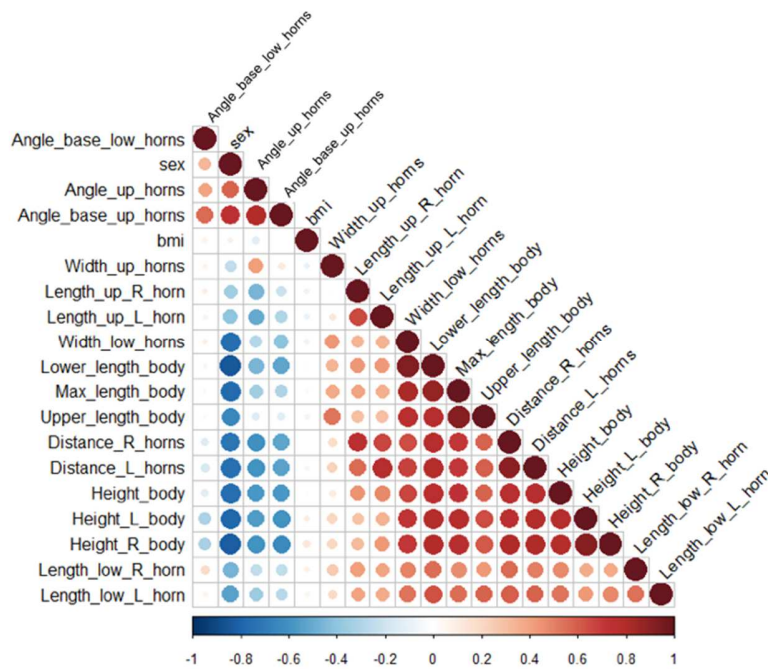


Figure 5: Correlation matrix

No correlation is observed between the BMI and any of the measurement. The angles do have a correlation between them. This matrix also shows a strong correlation between the different heights and lengths of the lamellar body. For the horns, the correlation is less important between the lengths of the upper and lower horns.

Another significant correlation is the one according to sex. The sex shows a positive correlation with the angles, associated to females and a negative correlation with lengths measurements, associated to males.

### 3.1.3. Decision tree

To refine these results, we used decision tree to identify whether some measures, or combinations of measurements, which could discriminate factors according to sex.

Only the lower length of the lamellar body differentiates the two sexes: above 28,69mm individuals are classified as males and as females below this threshold. This tree was also tested on one half of the sample to evaluate a 2,5% error rate.

### 3.1.4. Principal Component Analysis (PCA)

From the 17 measurements used in this study, we developed a PCA to determine 6 morphologies. It seems to show a distinction according to sex (fig. 6). We can notice that an individual is outlier, but the same test without this individual do not change the result. This individual was kept in our sample.

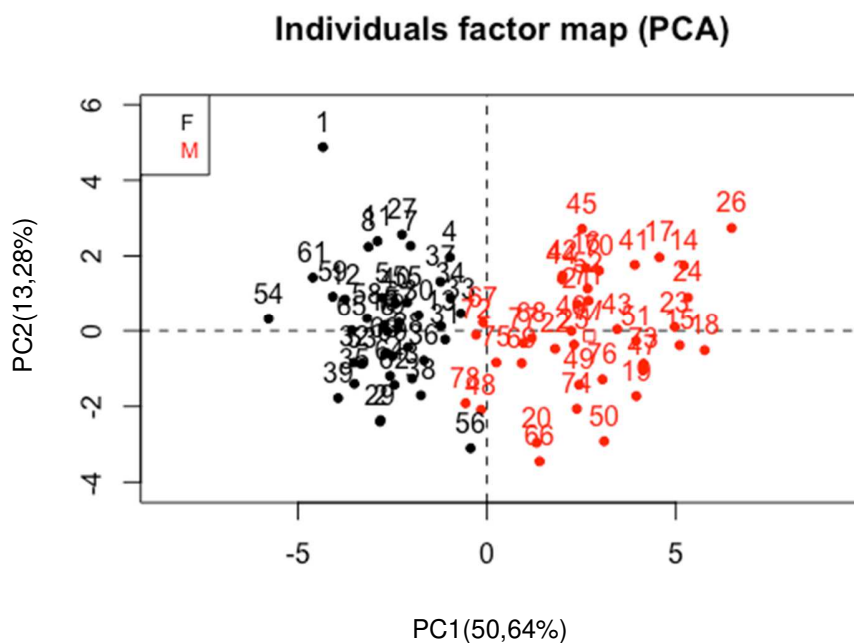


Figure 6: Principal component analysis

The first component represents 50,64% of the total variability of the sample, while the second component accounts for 13,28%. Our choice of individuals focused on the first principal component which explains half of the variability and is a linear combination of 6 measurements with weak contributions (see annex 1).

## 3.2. Models results

### 3.2.1. Numerical models

Twelve cases of strangulation were analyzed. It included the comparison according to sexes, to velocity and to robustness (gracile, intermediary and robust). At first, the injury assessment of the models was analyzed, then time and rupture stress were studied in each case (table 3 and 4).

In the injury assessment study (table 3), we observed that all models lead to fractures along the applied stress direction. Lesions are located at the upper horns. Except for 3 cases, each model presents bilateral fractures on the upper horns. In these cases, there is no preferential fractures sequence.

For a 1m/s imposed velocity, the intermediate and the robust male bone models present a unique unilateral fracture of the right upper horn. The gracile male model also shows a right unilateral fracture, but this time for a 0,4m/s imposed velocity, which was associated with a fracture of the lamellar body. Except for these 3 cases, the female and male models have similar behaviors.

		Bone	
		0,4m/s	1m/s
Gracile	Female	Upper horns	Upper horns
	Male	Upper right horn Median body	Upper horns
Intermediate	Female	Upper horns	Upper horns
	Male	Upper horns	Upper left horn
Robust	Female	Upper horns	Upper horns
	Male	Upper horns	Upper right horn

Table 3: Injury assessment

The results (table 4) show that the stress applied on the model do not depend on the velocity of the impactor. Independently of this parameter, we have thus observed a disparity of the results according to sex. The force required for the first fracture occurrence being 3 to 4 times higher for male models than for female models.

According to the morphologies, gracile models have weaker stresses than intermediate models. This pattern is the same for intermediate female models and robust female models. However, for male models, the stress values are a little higher in the case of the intermediate morphology than the robust morphology.

		Bone	
		0,4m/s	1m/s
Gracile	Female	386,00	421,56
	Male	1 337,11	1 268,93
Intermediate	Female	557,81	499,35
	Male	2 251,00	2 213,59
Robust	Female	899,63	989,80
	Male	2 051,05	1 915,16

Table 4: Force measurements at the first fracture (N)

#### 4. Discussion

This study presents a traumatological approach, associated to forensic science, whose main objective is to understand the neck injury mechanisms. Our approach was based on anthropometric data and allowed to develop biomechanical models of the thyroid cartilage. To our knowledge, no study has ever been performed in case of bi-digital strangulation.

Our low sample size limited our study, but the sample sex ratio is quite good with 51,3% of females and 48,7% of males. The approach based on CT scans exploitation make it possible to overcome the measurements bias related to the thyroid cartilage conservation. Indeed, the larynx structure is heterogeneous (more or less calcified) and thus unequally accessible to the measurements on ex situ organ. Thus, the measurements protocols found in literature were carried out on malleable larynxes that are therefore deformable and can be incompletely preserved [9,18–20].

The 17 measurements on thyroid cartilage made it possible to characterize the cartilage morphology, with correlation test showing a correlation between thyroid cartilage and the individual sex, as well as the proportions related to the cartilage, to each other. Among the 17 measurements studied, several of them have been described in literature [19, 21-25]. Most of the measurements show results in accordance with literature. However, some results may differ.

Measurements of height of the lamellar body raises questions. Indeed, our results differ from Kaur et al., 2015 and Ajmanji, 1990, especially for female individuals. Our measurements, for females, are 11,92mm +/-2,58mm, while the results obtained by Ajmanji, 1990 are around 17,35mm +/- 2,67mm and those of Kaur et al., 2015 around 16mm +/- 0,53mm. This divergence could potentially be explained by methodology differences, the authors having obtained thyroid cartilage from dissected larynx and not from scans. It could also be explained by the difference of sample sizes and the sex

ratios. Ajmani, 1990 used 40 cartilages (28 males and 12 females) and Kaur et al., 2015 had a sample of 30 cartilages but only 5 were females.

Since there is no consensus in literature concerning the characterization of the cartilage in human body [26–30], we have developed models with complete bone properties. The thyroid cartilage ossifies over time through a slow process, beginning at the end of puberty, and which is rarely completed [31]. The mean age of our sample ( $51.10 \pm 18.60$ ) is higher than the age associated to the beginning of the ossification process, which represent individuals with more ossified larynx than cartilaginous. The bone properties used in this study were derived from data already developed by the laboratory on the hyoid bone [1,2]. There was no specific characterization of thyroid cartilage subject to advanced ossification. Measurements and metric data thus obtained would require validation of the model by experiments on samples.

In our study, we have decided to understand bi-digital strangulation injury mechanisms. This first approach simulates a translation of two plates along the axis perpendicular to the thyroid cartilage. The different impactors used in the simulations were adapted to the size and form of each thyroid cartilage.

We do demonstrate that the behavior of the thyroid cartilage is not the same according to sex and morphology (gracile, intermediate and robust). For similar morphologies, the behavior between males and females was different. Indeed, the impact force required for the first fracture is from 3 to 4 times higher for males than female models. Overall, our simulations led to bilateral fractures (less than 1ms between the two horns fractures), except for 3 models (indicated with unilateral fracture in Table 3). For those models the second fracture occurred, at least, 3ms after the first one. Also, the impact force seems to depend on morphologies. However, the fractures locations were similar independently of sex and morphology.

## 5. Conclusion

This anthropometric and biomechanical study characterizes the thyroid cartilage with 17 measurements. Our results confirmed a significant sexual dimorphism on this cartilage shown in previous studies [17]. The models developed for a forensic purpose also demonstrated different behaviors according to sex and morphology.

Furthermore, these models allow a good visualization of cartilage behaviors in cases of strangulation. Further studies would be necessary to improve them and to characterize and model the traumas involving other parts of the larynx, in a forensic issue.

- [1] C. Lebreton-Chakour, Y. Godio-Raboutet, R. Torrents, K. Chaumoitre, C. Boval, C. Bartoli, P. Adalian, M.-D. Piercecchi-Marti, L. Thollon, Manual strangulation: Experimental approach to the genesis of hyoid bone fractures, *Forensic Science International*. 228 (2013) 47–51. doi:10.1016/j.forsciint.2013.02.014.
- [2] F. Niort, Y. Godio-Raboutet, R. Torrents, P. Adalian, G. Léonetti, M.-D. Piercecchi-Marti, L. Thollon, Transmission of force to the hyoid bone during manual strangulation: Simulation using finite element numerical models, *Forensic Science International*. 257 (2015) 420–424. doi:10.1016/j.forsciint.2015.10.013.
- [3] V.D. Khokhlov, Injuries to the hyoid bone and laryngeal cartilages:: Effectiveness of different methods of medico-legal investigation, *Forensic Science International*. 88 (1997) 173–183. doi:10.1016/S0379-0738(97)00101-1.
- [4] B. Bockholdt, M. Hempelmann, H. Maxeiner, Experimental investigations of fractures of the upper thyroid horns, *Legal Medicine*. 5 (2003) S252–S255. doi:10.1016/S1344-6223(02)00142-6.
- [5] H. Maxeiner, B. Bockholdt, Homicidal and suicidal ligature strangulation—a comparison of the post-mortem findings, *Forensic Science International*. 137 (2003) 60–66. doi:10.1016/S0379-0738(03)00279-2.
- [6] B. Singh, S. Kumar, V. Kumar, Blunt laryngotracheal injury following accidental strangulation, *International Journal of the Care of the Injured*. 34 (2003) 937–939.
- [7] M.S. Pollanen, D.N. McAuliffe, Intra-cartilaginous laryngeal haemorrhages and strangulation Presented at the 17th Congress of the International Academy of Legal Medicine, Dublin, Ireland, August 20–23, 1997.1, *Forensic Science International*. 93 (1998) 13–20. doi:10.1016/S0379-0738(98)00024-3.
- [8] P. Fais, C. Giraud, A. Viero, D. Miotto, F. Bortolotti, F. Tagliaro, M. Montisci, G. Cecchetto, Micro computed tomography features of laryngeal fractures in a case of fatal manual strangulation, *Legal Medicine*. 18 (2016) 85–89.
- [9] M.. Ajmani, S.. Jain, S.. Saxena, A metrical study of laryngeal cartilages and their ossification, *Anatomischer Anzeiger*. 148 (1980) 42–48.
- [10] T. Plattner, S. Bolliger, U. Zollinger, Forensic assessment of survived strangulation, *Forensic Science International*. 153 (2005) 202–207. doi:10.1016/j.forsciint.2004.09.106.
- [11] J. Rajs, I. Thiblin, Histologic appearance of fractured thyroid cartilage and surrounding tissues, *Forensic Science International*. 114 (2000) 155–166. doi:10.1016/S0379-0738(00)00299-1.
- [12] P. Hejna, M. Janík, P. Urbanová, Agenesis of the Superior Cornua of the Thyroid Cartilage: A Rare Variant of Medicolegal Importance, *The American Journal of Forensic Medicine and Pathology*. 36 (2015) 10. doi:10.1097/PAF.0000000000000131.
- [13] H. Claassen, M. Schicht, S. Sel, F. Paulsen, Special pattern of endochondral ossification in human laryngeal cartilages: X-ray and light-microscopic studies on thyroid cartilage, *Clinical Anatomy*. 27 (2014) 424–430.
- [14] H.M. Garvin, Ossification of Laryngeal Structures as Indicators of Age, *Journal of Forensic Sciences*. (2008)
- [15] S. Türkmen, A. Cansu, S. Türedi, U. Eryigit, A. Sahin, A. Gündüz, I. Shavit, Age-dependent

structural and radiological changes in the larynx, *Clinical Radiology*. 67 (2012) e22–e26.  
doi:10.1016/j.crad.2012.07.006.

[16] J. Pollard, M.D. Piercecchi-Marti, L. Thollon, C. Bartoli, P. Adalian, A. Bécart-Robert, G. Tournel, V. Hédouin, M. Panuel, D. Gosset, G. Leonetti, Mechanisms of hyoid bone fracture after modelling: Evaluation of anthropological criteria defining two relevant models, *Forensic Science International*. 212 (2011) 274.e1-274.e5. doi:10.1016/j.forsciint.2011.06.020.

[17] J. Wysocki, E. Kielska, P. Orszulak, J. Reymond, Measurements of pre- and postpubertal human larynx: a cadaver study, *Surg Radiol Anat*. 30 (2008) 191–199. doi:10.1007/s00276-008-0307-8.

[18] H.E. Eckel, C. Sittel, P. Zorowka, A. Jerke, Dimensions of the laryngeal framework in adults, *Surg Radiol Anat*. 16 (1994) 31–36. doi:10.1007/BF01627918.

[19] M.L. Ajmani, A metrical study of the laryngeal skeleton in adult Nigerians., *J Anat*. 171 (1990) 187–191.

[20] H.E. Eckel, C. Sittel, Morphometry of the larynx in horizontal sections, *American Journal of Otolaryngology*. 16 (1995) 40–48. doi:10.1016/0196-0709(95)90008-X.

[21] R. Kaur, Department of Anatomy, Gian Sagar Medical College and Hospital, Banur, Patiala, Punjab, India., V. Laxmi, Department of Anatomy, Government Medical College, Amritsar, Punjab, India., MORPHOLOGY AND MORPHOMETRY OF ADULT HUMAN CRICOID CARTILAGE: A CADAVERIC STUDY IN NORTH INDIAN POPULATION, *International Journal of Anatomy and Research*. 3 (2015) 910–914. doi:10.16965/ijar.2015.109.

[22] M. Jain, U. Dhall, Morphometry Of The Thyroid And Cricoid Cartilages In Adults, *J. Anat. Soc. India*. (2008) 5.

[23] D. Park, D. Kim, U. Lee, K. Han, K. Kim, S. Han, Morphometric analysis of the Koreans thyroid cartilage for identification of sex: metric Study, *Korean Journal of Physical Anthropology*. 16 (2003) 129–136.

[24] M.M. Joshi, S.S. Joshi, Professor and Head, Department of Anatomy, Arbindo Institute of Medical Sciences, Indore, Madhya Pradesh, India., S.D. Joshi, Dean, Arbindo Institute of Medical Sciences, Indore, Madhya Pradesh, India., MORPHOMETRIC STUDY OF THYROID CARTILAGES IN WESTERN INDIA, *International Journal of Anatomy and Research*. 3 (2015) 1028–1033. doi:10.16965/ijar.2015.150.

[25] G. Jotz, M. Stefani, O. Da Costa Filho, T. Malysz, P. Soster, H. Leao, A morphometric study of the larynx, *Journal of Voice*. 28 (2014) 668–672.

[26] Q. Xue, X. Zheng, R. Mittal, S. Bielałowicz, Computational Study of Effects of Tension Imbalance on Phonation in a Three-Dimensional Tubular Larynx Model, *Journal of Voice*. 28 (2014) 411–419. doi:10.1016/j.jvoice.2013.12.016.

[27] J. Yin, Z. Zhang, Interaction between the thyroarytenoid and lateral cricoarytenoid muscles in the control of vocal fold adduction and eigenfrequencies, *J Biomech Eng*. 136 (2014). doi:10.1115/1.4028428.

[28] Y. Zhang, T. Shi, The research of laryngeal joints to reconstruction an modeling, *Bio-Medical Materials and Engineering*. 24 (2014) 2627–2634.



- [29] J. Zhao, G. Narwani, Development of human body finite element model for restraint system R&D applications, in: 2005.
- [30] J. Zhao, G. Narwani, Biomechanical Analysis of Hard Tissue Responses and Injuries with Finite Element Full Human Body Model, in: 2007.
- [31] K.-D. Dang-Tran, F. Dedouit, F. Joffre, D. Rougé, H. Rousseau, N. Telmon, Thyroid Cartilage Ossification and Multislice Computed Tomography Examination: A Useful Tool for Age Assessment?, *Journal of Forensic Sciences*. 55 (2010) 677–683. doi:10.1111/j.1556-4029.2010.01318.x.

## Annex 1

Variables	PC 1 (%)	PC 2 (%)
Distance right horns	9,14	0,36
Distance left horns	9,23	0,34
Width upper horns	0,79	19,70
Width lower horns	7,41	4,59
Length upper right horn	3,57	0,25
Length upper left horn	4,06	1,03
Angle upper horns	4,33	19,81
Height lamellar body	8,09	0,42
Height left lamellar body	8,14	0,44
Height right lamellar body	8,56	0,90
Maximum length lamellar body	8,11	3,89
Upper length lamellar body	6,10	10,33
Lower length lamellar body	9,32	1,32
Length lower right horn	3,87	2,54
Length lower left horn	4,90	1,58
Angle bases upper horns	4,07	16,09
Angle bases lower horns	0,32	16,38

*Table 2: Contribution of the measurements for the PCA*