Systematic review

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The Multidisciplinary Approach for the Diagnosis of Laryngohyoid Lesions: a Systematic Literature Review and Meta-Analysis

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Abstract

Background. The diagnosis of neck lesions remains a medico-legal diagnostic challenge because of the complexity of the anatomical relationship of the neck's organs and their anthropometric morphological variability. We compared the multidisciplinary approach using autopsy and postmortem computed tomography (PMCT), postmortem fine preparation (PMFP), postmortem micro-computed tomography (micro-CT), and postmortem magnetic resonance (PMMR) with the performance of a single diagnostic method among them evaluating the significance of different results. The multidisciplinary approach significantly reduced the number of unidentified neck lesions. The analysis demonstrates the need to better define the scan protocols and compose forensic guidelines for radiological application. The results of this study point out the need to compare the different diagnostic approaches in deceased subjects to better define the radiological scan protocol based on a multidisciplinary approach, including autopsy and radiological methods and the radiological scan protocols.

Methods. We performed a systematic electronic search of retrospective scientific articles in PubMed, the Scopus database, and the Cochrane Library. The following combinations of words were used: "hyoid fracture"; "comparison between PMCT AND autopsy"; "hyoid fracture PMCT AND autopsy"; "hyoid bone fracture AND forensic imaging"; "hyoid fracture AND PMCT"; "neck fracture PMCT AND autopsy"; "laryngohyoid lesions"; "postmortem CT AND autopsy in strangulation"; "postmortem AND strangulation Signs "; "strangulation virtopsy"; and "strangulation AND MRI". We selected 16 articles that were published between March 2003 and June 2020. We conducted a meta-analysis with R software to evaluate the rates. We obtained related confidence intervals and a forest plot.

Results. Thyroid cartilage damages were significantly more common than hyoid bone fractures (61.7% vs 42.2%) in a sample of 128 subjects. The synergic uses of autopsy/PMCT, autopsy/PMFP, autopsy/microCT, and autopsy/PMMR revealed significantly higher rates than a single investigation. We analyzed the PMCT scan data. The scan parameters evaluated were as follows: row, scan sample, reconstruction, kernel, slice thickness, kVp, and mAs. A lack of uniformity in the application of the protocol was observed.

Conclusion. Further studies are needed to better define the radiological scan protocols and to draw guidelines to identify the appropriate radiological methods in relation to the specific case. ***Clin Ter 2023; 174 (1):97-108 doi: 10.7417/CT.2023.2504***

Key words: *laryngohyoid lesions, hyoid bone fractures, thyroid cartilage lesions, autopsy, PMCT, magnetic resonance*

Introduction

The diagnosis of laryngohyoid lesions remains a medico-legal diagnostic challenge because of the complexity of the anatomical relationship of the neck's organs and their morphological variability (1, 2).

The conviction or acquittal for murder depends on the correct diagnosis of mechanical asphyxia from external compression by means of adequate signs observed at the autopsy table; therefore, such signs are of considerable importance to the criminal justice system. The difficulty also lies in the wide spectrum of injuries associated with the application of an external compressive force in this region. There are five main elements that are difficult to analyze during an inspection of the neck: the complex anatomy of the hyoid bone; inspection of the triticeous cartilage; Prinsloo–Gordon hemorrhage; hypostatic cervical congestion; injury to the neck related to trauma/resuscitation maneuvers (3). Hemorrhage in the anterior compartment of the neck may be due to hypostatic phenomena; Prinsloo and Gordon artifacts may result from violent movements of the neck, due to resuscitation, compression, or trauma.

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Laryngohyoid lesions are difficult to identify because of the complexity of the anatomical relationship and structural weakness of the neck's organs, their anthropometric morphological variability, and the presence of micro-fractures (3). The complexity of anatomical neck structures and their morphological variability concerns both the hyoid bone and laryngeal components. There are different forms of hyoid bone: hyperbolic, parabolic, horseshoe-shaped, or a combination of these; fracture of the great horns concerns mainly the hyperbolic shape, vertical fractures, and parabolic shape (4). The degree of ossification and the morphology of the larynx (frail, intermediate, or robust) influence the development of the fractures (1).

Comparison between conventional autopsy and the several radiological procedures, such as postmortem computed tomography (PMCT), postmortem fine preparation (PMFP), micro-computed tomography (microCT), or postmortem magnetic resonance (PMMR) for the diagnosis and identification of injuries is fundamental for identifying a better diagnostic approach. Radiological techniques are increasingly used in daily practice and differ depending on tissue characteristics; postmortem magnetic resonance (PMMR) is the most appropriate procedure among radiological techniques to diagnose soft tissue hemorrhage (5); computed tomography (CT) is the best for bone and cartilage injuries (6). The modern literature on the comparison between the performance of autopsy and radiology is still controversial (7). Recently, it has been stated that a synergic use of radiological procedures and autopsy allows for decreasing the number of missed lesions (8), although the two procedures confirm the same diagnosis in many cases (9).

The maximum possible correspondence between radiological and autoptic findings was observed with innovative postmortem fine preparation (PMFP) (10), which is a useful radiological support, especially in the context of the quantification of a trauma's extent, that is performed after organ explant (11).

Given the absence of the medico-legal guidelines about the postmortem diagnostic approach to neck lesions, this study points out the need to compare the different diagnostic approaches in deceased subjects. We compared the results of the autopsy and radiological techniques, as well as a combined approach using autopsy and postmortem radiology, to better define the advantages of the multidisciplinary approach in the postmortem diagnosis of neck lesions. In addition, the absence of a specific radiological scan protocol for each analyzed radiological technique has emerged from the analysis.

Materials and Methods

In this study, we performed a systematic electronic search of retrospective scientific articles comparing postmortem radiology and autopsy investigation of laryngohyoid lesions. We searched scientific articles in Pubmed (MEDLINE), the Scopus database, and the Cochrane Library (including the Cochrane Central Register of Controlled Trials), filtering with the following eligibility criteria: English language; types of study (case reports, classical article, journal article, clinical trial, meta-analysis, randomized controlled trial, review, systematic review), and human species. The following combinations of words were used: "hyoid fracture"; "comparison between PMCT AND autopsy"; "hyoid fracture PMCT AND autopsy"; "hyoid bone fracture AND forensic imaging"; "hyoid fracture AND PMCT"; "neck fracture PMCT AND autopsy"; "laryngohyoid lesions".

Due to the limited number of articles extrapolated, we had to extend the search with the following additional word combinations: "postmortem CT AND autopsy in strangulation"; "postmortem AND strangulation signs"; "strangulation virtopsy"; "strangulation AND MRI". These combinations allowed us to implement data regarding the manner of death to make the sample more homogeneous and to improve the statistical analysis.

We found 252 articles: 136 on Pubmed, 113 on Scopus, and 3 on Cochrane.

After removing 109 duplicate records, there were 143 remaining articles.

We examined the titles and abstracts of 21 articles and we read the full text of 18 of them. We selected 16 articles published between March 2003 and June 2020 (Fig. 1): 15 (12-26) were articles and one (27) was a review (5).

The inclusion criteria were as follows: English language; title and abstract related to comparison between PMCT/MRI and autopsy in hyoid bone fractures; full-text articles concerning radiological and autopsy investigation in strangulation deaths with hyoid bone fractures.

We applied the following exclusion criteria: studies not concerning laryngohyoid lesions; languages other than English; studies without hyoid fractures; studies without a comparison between postmortem radiological data and autopsy findings.

We divided the articles according to the topics, reporting titles, authors, publication date, number of subjects, and study results (Table 1). We also extrapolated data concerning soft-tissue neck injuries from the selected studies.

Statistical Analysis

The statistical analyses were developed from R software. The rate of injury was the main object of measurement for the study. The prevalence of different types of death and diagnostic techniques was calculated, and we obtained the related confidence intervals (IC95%). IC95% represents a 95% confidence interval; it allows for estimating the rate with an error rate of 5%. We applied significance tests for the comparison of some subgroups. We compared the different rates using a forest plot, which allowed for analyzing the heterogeneity among the studies to verify the reliability of the global measure summarizing the data of each study. For the sake of completeness, all excluded studies were taken into consideration in the global analysis of each topic.

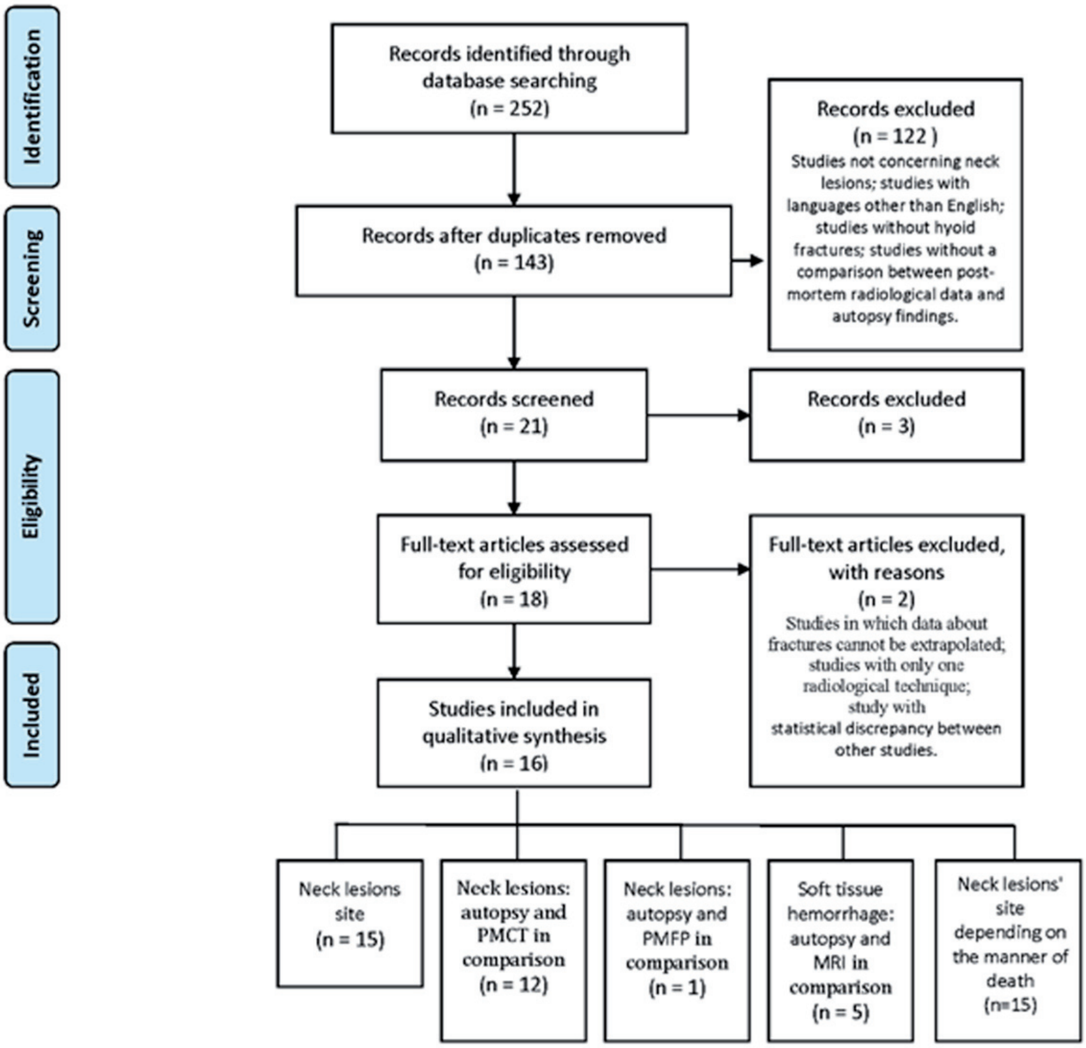

Fig. 1. PRISMA Flow Diagram

Results

Lesions Localization

Hyoid bone lesions occurred in 42.2% of the cases (Fig. 2.a) in the analyzed studies reporting these data (12-25, 27).

Thyroid cartilage lesions were involved in 61.7% of the cases, with the prevalence of the superior thyroid horns (Figure 2.b). We excluded one study (12) in which the thyroid cartilage legions were dependent on multiple cartilage lesions in each subject and had a consequent rate greater than 1. All studies had a high rate (>50%) except for three (19, 22, 27). We did not find cricoid lesions to be relevant because only a small sample size had cricoid damage.

We found high heterogeneity among the rates of soft tissue lesions; however, we did not consider the global measure to be entirely reliable, which was equal to 48.4% (Figure 2.c). Thyroid cartilage injuries were significantly more common than hyoid bone fractures (p-value = 0.00268).

The involvement of hyoid bone and soft tissue injuries occurred with the same frequency (p-value = 0.3795). We cannot claim with certainty that there was a prevalent injury type between soft tissue hemorrhage and thyroid cartilage lesions (p-value = 0.04439).

Lesions' Sites depending on the Manner of Death

Suicides represent 65.6% of the 128 cases, homicides 31.25%, and accidents 3.1% in the fifteen analyzed studies (8-21, 23).

Suicides

The analyzed studies (14, 16, 18-21, 23) had similar moderately low rates of hyoid lesions (Figure 3.a) except for two studies (18, 23), which, however, had samples of a single and two deaths, respectively. We noted that 41% of the suicides presented hyoid fractures (Figure 3.a). Five

Table 1. Analyzed studies.

				Neck lesion site independentely of cause of death			Neck lesion site dependentely of cause of death						Match between autopsy and radiological techniques		
							Omicides			Suicides					
Study	Year	Type of Study	Study Size	Proportion of hyoid bone lesion	Proportion of thyroid cartilage lesion	Proportion of soft tissue hemorrhage	Proportion of hyoid bone lesion	Proportion of thyroid cartilage lesion	Proportion of soft tissue hemorrhage	Proportion of hyoid bone lesion	Proportion of thyroid cartilage lesion	Proportion of soft tissue hemorrhage	Proportion of osteo-cartilagineum lesions found thourgh match between autopsy and PMCT	Proportion of soft tissue hemorrhage found thourgh match between autopsy and PMCT	Proportion of soft tissue hemorrhage found thourgh match between autopsy and MRI
BAIER M. ET AL (12)	2019	Case series	10	0.30	0.67	0.00	0.30	0.67	0.67	-	-	-	0.68	0.00	-
BAIER M. ET AL (13)	2019	Case series	3	0.33	-	0.67	0.33	-	-	-	-	-	-	-	-
CHARLIER P. ET AL (14)	2011	Retrospective	3	1.00	0.67	0.67	-	-	-	-	-	-	-	-	-
DE BAKKER H.M. ET AL (15)	2020	Retrospective	11	0.82	0.73	0.00	0.82	0.73	-	-	-	-	0.64	-	-
DENINGER CZEMARK E. ET AL (16)	2020	Retrospective	6	0.33	0.67	0.83	0.33	0.68	0.83	-	-	-	0.83	0.75	0.80
FAIS P. ET AL (17)	2016	Case series	7	0.00	1.00	1.00	-	1.00	1.00	-	-	-	-	-	-
KEMPTER M. ET AL (18)	2009	Retrospective	3	0.38	0.88	0.75	0.50	-	1.00	0.40	0.60	0.60	0.89	0.17	-
KETTNER M. ET AL (19)	2014	Case series	2	0.00	1.00	0.00	-	1.00	-	-	-	-	1.00	0.00	-
LE BLANC-LOUVRY I. ET AL (20)	2013	Case series	11	0.55	0.00	1.00	-	-	-	0.45	-	1.00	0.83	0.18	-
MAIESE A. ET AL (21)	2014	Case series	1	0.00	1.00	1.00	-	1.00	-	-	-	-	1.00	0.00	-
POLACCO M. ET AL (22)	2013	Case series	1	1.00	0.00	1.00	-	-	-	1.00	-	1.00	1.00	1.00	-
SHULZE K. ET AL (23)	2018	Retrospective	35	0.31	0.57	0.00	-	-	-	0.31	0.57	-	1.00	-	-
THALI M.J. ET AL (27)	2003	Case series	2	1.00	0.50	1.00	-	-	-	1.00	0.50	1.00	0.67	0.00	0.50
YEN K. ET AL (24)	2005	Retrospective	9	0.44	0.22	0.89	0.25	0.25	1.00	0.60	0.20	0.80	0.83	1.00	1.00
DENINGER CZEMARK E. ET AL (25)	2020	Retrospective	25	0.36	0.60	0.92	-	-	-	0.36	0.60	0.92	0.50	-	0.29
DUBAND S. ET AL (26)	2009	Case series	5	-	-	-	-	-	-	-	-	-	-	-	1.00
Globale Measure	-	-	-	0.422	0.617	0.484	0.425	0.90	0.375	0.41	0.48	0.52	0.77	0.441	0.58

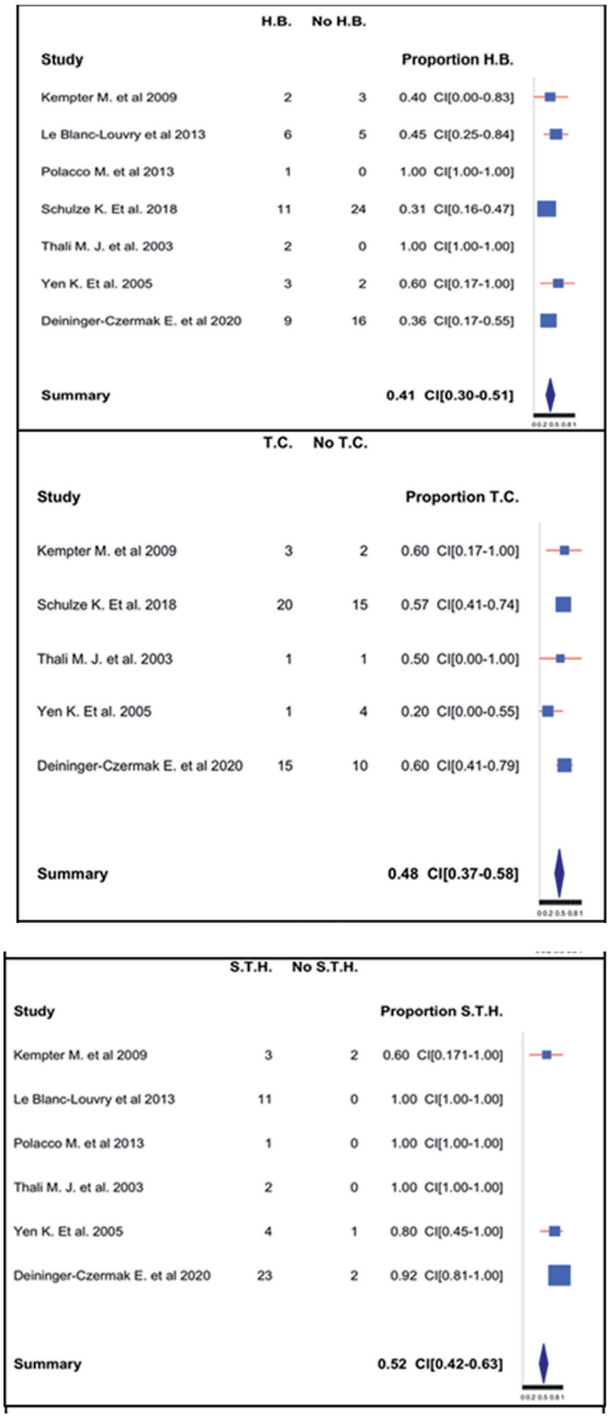

Fig. 2. (a). Proportions of hyoid bone lesions independently of cause of death: forest plot; (b) proportions of thyroid cartilage lesions in the sample independently of cause of death: forest plot. (c) proportions of soft tissue hemorrhage in the sample independently of cause of death: forest plot.

studies (14, 19, 20, 21, 23) presented a high rate of thyroid cartilage injury (Fig. 3.b), equal to or above 50%; only one study (20) had a low rate. Only two studies (14, 21) showed similar high rates. We observed that 48% of the suicides involved thyroid cartilage.

Finally, we investigated the rates of neck soft tissue hemorrhage in suicides by analyzing six studies (14, 16, 18, 20, 21, 23), as shown in the following forest plot (Fig. 3.c). Only one study (19) had a rate equal to zero, which influenced the overall analysis because of its large sample size; three studies (16, 18, 23) had high rates. We identified neck soft tissue hemorrhage in 52% of the suicides. Sternocleidomastoid was the most involved muscle in suicides (26.1% of cases).

The cricoid cartilage was damaged in only three suicides reported in only one study (19).

The six analyzed studies (8, 9, 11, 12, 14, 20) did not have similar rates of hyoid bone lesions, as shown in the forest plot (Fig. 4.a). The studies with a small sample presented low rates. We combined the data to produce a rate equal to 42.5%. We conducted the same analysis using seven studies (9, 11-13, 15, 17, 20) on thyroid cartilage lesions and found very similar rates in several studies (Fig. 4.b)— 90% of the homicides involved thyroid cartilage. Two studies (8, 14) were excluded because their ratios were greater than 1. The right and/or left greater horns of the hyoid bone and the right and/or left superior thyroid horns were the most damaged parts. The cricoid cartilage was injured in only two murdered subjects (13, 14).

In the six analyzed studies (9, 12-14, 17, 20), 37.5% of the homicides presented soft tissue hemorrhage (Fig. 4.c). The sternocleidomastoid was injured in 12.5% of the homicides.

Accidents

Our descriptive analysis of two studies (10, 14) shows that the hyoid bone and thyroid cartilage were fractured in 75% of the accidents; the sternocleidomastoid was damaged in one case.

Comparison between Percentages of Lesions Site depending on the Manner of Death

There was not a significant difference (p-value = 0.9849) between the percentages of hyoid bone lesions in homicides (42.5%) and suicides (40.5%). We found that all three manners of death (homicides, suicides, and accidents) involved mainly the right and/or left greater horn, although we did not take into consideration the numerous studies that did not report these data. There was a significant difference (p-value = 0.00995) between the percentages of thyroid cartilage lesions in homicides (90%) and suicides (47.6%). Almost all the studies did not specify the involved part of cartilage in suicides; however, right and/or left superior thyroid horns were the cartilage parts most commonly injured in homicides. Soft tissue hemorrhage occurred in 37.5% of the homicides and 52.4% of the suicides, with a non-significant difference (p-value = 0.1742). The sternocleidomastoid muscle was the soft tissue most often damaged in suicides, with a high percentage (26.19%); it was involved only in 12.5% of the homicides.

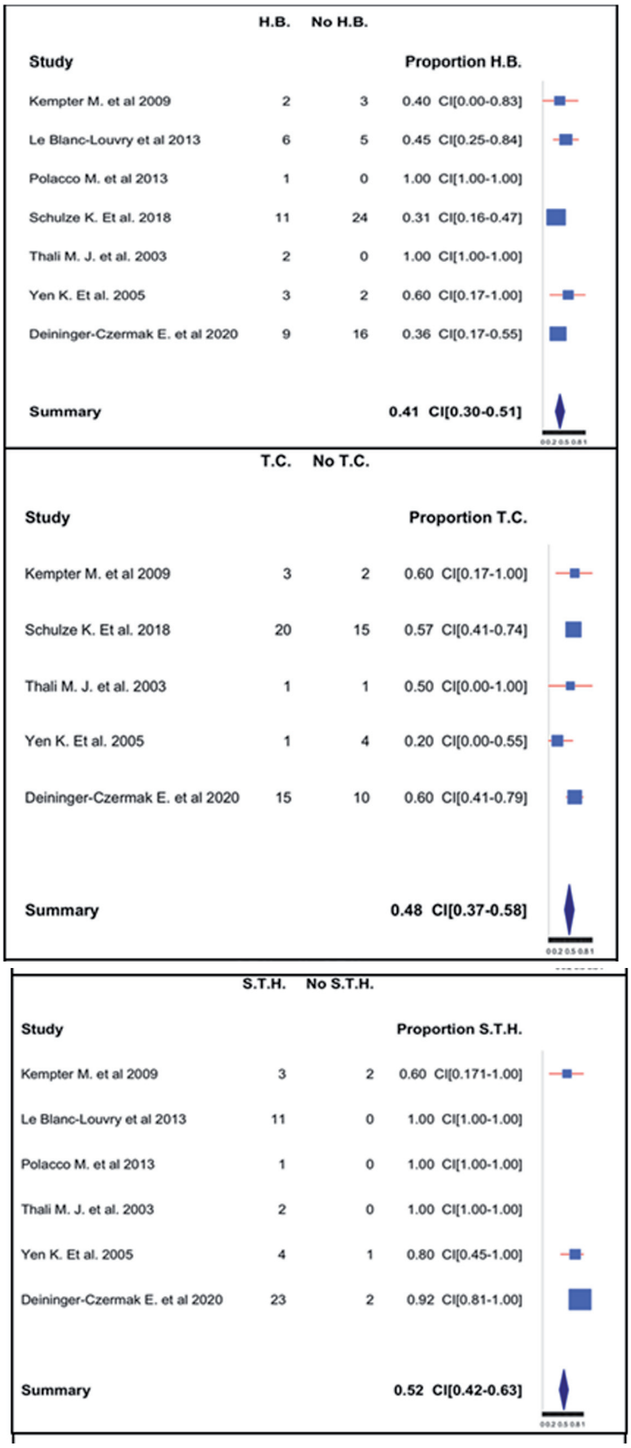

Fig. 3. (a) Proportions of hyoid bone lesions in suicides: forest plot; (b) proportions of thyroid cartilage lesions in suicides: forest plot; (c) proportions of soft tissue hemorrhage in suicides: forest plot.

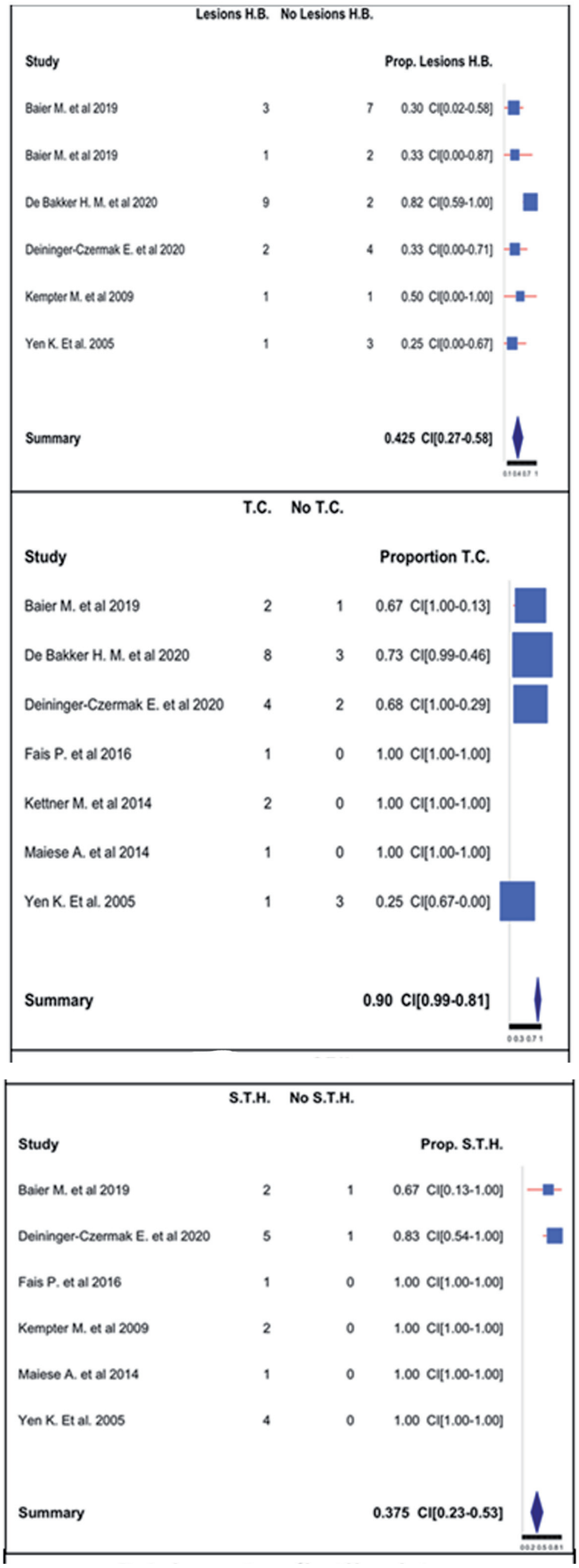

Fig. 4. (a) Proportions of hyoid bone lesions in homicides: forest plot; (b) proportions of thyroid cartilage lesions in homicides: forest plot; (c) proportions of soft tissue hemorrhage in homicides: forest plot.

Autopsy, PMCT, PMFP and microCT and PMMR in Comparison

We compared autopsy with radiological procedures and their agreement regarding the postmortem diagnosis of laryngohyoid lesions. The following procedures were compared: autopsy and PMCT; autopsy and PMFP; autopsy and micro-CT; autopsy and PMMR.

Comparison between Autopsy and PMCT

Twelve studies (13,15, 16,18, 19-25, 27) compared autopsy with PMCT findings.

There was fairly high agreement regarding bone and cartilage tissue lesions, equal to 77% (Figure 5.a); only one study (25) differed. Agreement was low regarding the identification of soft tissue hemorrhage (44.1%) despite the small sample size (Fig. 5.b).

Agreement between the results of autopsy and PMCT included 67.6% of all the injuries from the different tissues; only autopsy included 18.5% and only PMCT included 13.9%. More specifically, 74.4% of the bone or cartilage injuries were included; only autopsy included 7.7% and only PMCT included 18% (Table 2). The combination of both investigations had a significantly higher rate than a single investigation (p-value <0.05). Autopsy did not identify a significantly different rate of injuries compared to PMCT (p-value = 0.349). The small sample size did not allow for drawing firm conclusions.

The combination of both methods identified significantly more (p-value <0.05) osteocartilaginous injuries than only autopsy or only PMCT. Only PMCT delivered significantly (p-value <0.05) better results than only autopsy in the diagnosis of bone and cartilage injuries.

Only autopsy detected 55.9% of the hemorrhages and agreement occurred in only 44.1% of the cases with a non-significant difference (p-value = 0.4669).

Comparison between Autopsy and microCT

The global measure showed that 66.67% of osteocartilaginous lesions were detected by both autopsy and microCT in one study (13) and 100% of them were detected by both in another (19) (Table 2).

Comparison between Autopsy and PMFP

Agreement between these procedures included 82% of the hyoid bone lesions and 63.7% of the cartilage lesions in the only study comparing autopsy with PMFP (15); only autopsy provided better results than only PMFP regarding the identification of cartilage lesions (27.3% vs 9.1%) (Table 3).

The combination of autopsy/PMFP identified a significantly (p < 0.05) higher rate of thyroid cartilage injuries than a single investigation. The comparison between only autopsy and only PMFP did not result in significant differences (p-value= 0.185). The use of both procedures seemed to be significantly (p-value < 0.05) more adequate than the use of a single investigation, enabling better identification of injuries (72.3%).

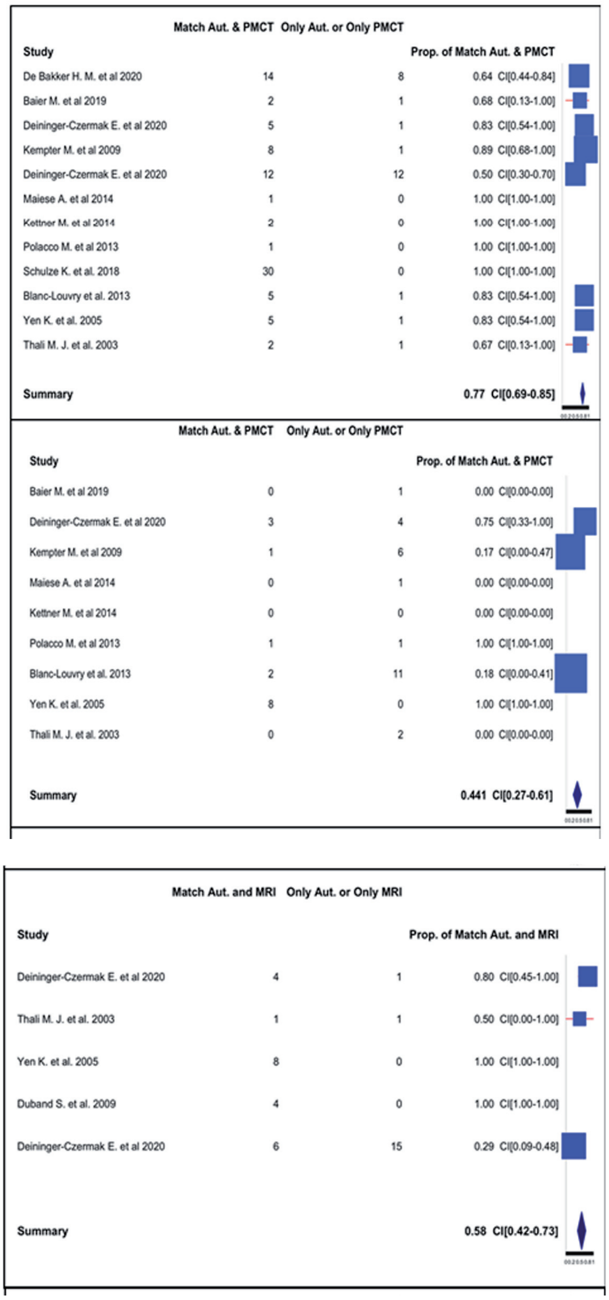

Fig. 5. (a) Proportion of the match between autopsy and PMCT for bone or cartilage lesions: forest plot; (b) proportions of the match between autopsy and PMCT for soft tissue hemorrhage: forest plot; (c) proportions of the match between autopsy and PMMR for soft tissue hemorrhage: forest plot.

Table 2. Neck lesions: autopsy and PMCT in comparison.

Tab 2 - Neck lesions: autopsy and PMCT in comparison																	
Articles	Sample size	Radiological Procedure	Match between Autopsy and PMCT					Only autopsies					Only radiological scans: PMCT				
			Bone or Cartilage lesions			Bone or Cartilage lesions	Soft tissue hemorhage	Bone/Cartilage lesions			Bone or Cartilage lesions	Soft tissue hemorhage	Bone/Cartilage lesions			Bone or Cartilage lesions	Soft tissue hemorhage
			Hyoid	Thyroid	Cricoid			Hyoid	Thyroid	Cricoid			Hyoid	Thyroid	Cricoid		
De Bakker H. M. et al 2020 (15)	11	CT	72,73%	54.55%	-	63.64%	NA	9.09%	36.36%	-	22.73%	NA	18.18%	9.09%	-	13.64%	NA
Baier M. et al 2019 (13)	3	microCT	100.00%	50.00%	-	66.67%	0.00%	0.00%	0.00%	-	0.00%	100.00%	0.00%	50.00%	-	33.33%	0.00%
Deininger-Czermak E. et al 2020 (16)	6	CT	50,00%	100.00%	-	83.33%	75.00%	0.00%	0.00%	-	0.00%	25.00%	50.00%	0.00%	-	16.67%	0.00%
Kempter M. et al 2009 (18)	8	CT	100.00%	83.33%	0.00%	80.00%	16.67%	0.00%	0.00%	0.00%	0.00%	83.33%	0.00%	16.67%	100.00%	20.00%	0.00%
Deininger-Czermak E. et al 2020 (25)	25	CT	44.44%	53.33%	-	50.00%	NA	11.11%	6.67%	-	8.33%	NA	44.44%	40.00%	-	41.67%	NA
Maiese A. et al 2014 (21)	1	CT	-	100.00%	-	100.00%	0.00%	-	0.00%	-	0.00%	100.00%	-	0.00%	-	0.00%	0,00%
Kettner M. et al 2014 (19)	2	msCT and mfCT	-	100.00%	-	100.00%	-	-	0.00%	-	0.00%	-	-	0.00%	-	0.00%	-
Polacco M. et al 2013 (22)	1	CT	100.00%	-	-	100.00%	100.00%	0.00%	-	-	0.00%	0.00%	0.00%	-	-	0.00%	0,00%
Schulze K. et al. 2018 (23)	35	CT	100.00%	100.00%	0.00%	90.91%	NA	0.00%	0.00%	33.33%	3.03%	NA	0.00%	0.00%	66.67%	6.06%	NA
Blanc-Louvry et al. 2013 (20)	11	CT	83.33%	-	-	83.33%	18.18%	16.67%	-	-	16.67%	81.82%	0.00%	-	-	0.00%	0,00
Yen K. et al. 2005 (24)	9	msCT	75.00%	100.00%	-	83.33%	100.00%	0.00%	0.00%	-	0.00%	0.00%	25.00%	0.00%	-	16.67%	0,00
Thali M. J. et al. 2003 (27)	2	msCT	50.00%	100.00%	-	66.67%	0.00%	0.00%	0.00%	-	0.00%	100.00%	50.00%	0.00%	-	33.33%	0,00
Overall	114		76.00%	77.78%	0.00%	74.36%	44.12%	6.00%	7.94%	25.00%	7.69%	55.88%	18.00%	14.29%	75,00%	17.95%	0.00%

PMCT= post-mortem computed tomography; CT= computed tomography; msCT= multislice computed tomography; MRI= magnetic resonance imaging; NA: not available

Table 3. Neck lesions: proportion about the comparison between autopsy and PMFP.

Tab. 3 - Neck lesions: autopsy and PMFP in comparison																
Article	Sample size	Match between Autopsy and PMFP (CT explant)					Only autopsy					Only radiological scans: PMFP (CT explant)				
		Bone or Cartilage lesions				Soft tissue hemorhage	Bone or Cartilage lesions				Soft tissue hemorhage	Bone or Cartilage lesions				Soft tissue hemorhage
		Hyoid	Thyroid		Cricoid		Hyoid	Thyroid		Cricoid		Hyoid	Thyroid		Cricoid	
			Cartilage	Lamina				Cartilage	Lamina				Cartilage	Lamina		
De Bakker H. M. et al 2020 (11)	11	81.82%	63.64%		-	-	18.18%	27.27%		NA	-	0.00%	9.09%		-	-

PMFP= post-mortem fine preparation; CT: computed tomography.

Tab. 4 - Soft tissue hemorrhage: autopsy and MRI in comparison

Articles	Sample size	Match between Autopsy and MRI	Only autopsies	Only radiological scans: MRI	Total Soft Tissue Hemorrhage
Deininger-Czermak E. et al 2020 (16)	6	80.00%	0.00%	20.00%	100.00%
Thali M. J. et al. 2003 (27)	2	50.00%	50.00%	0.00%	100.00%
Yen K. et al. 2005 (24)	9	100.00%	0.00%	0.00%	100.00%
Duband S. et al. 2009 (26)	5	100.00%	0.00%	0.00%	100.00%
Deininger-Czermak E. et al 2020 (25)	25	28.57%	28.57%	42.86%	100.00%
Overall	47	57.50%	17.50%	25.00%	100.00%

MRI= magnetic resonance imaging.

Comparison between Autopsy and PMMR

All analyzed studies (16, 24-27) showed similar rates of agreement except for one (25), which increased the margin of error in estimating the global measure because of its large sample size (Fig. 5.c). The global measure showed that 58% of lesions were detected in agreement; PMMR detected 25% and autopsy detected 17.5% (Table 4). The rates of soft tissue hemorrhage identified in agreement were significantly different (p-value <0.05). The comparison between the rates of lesions detected with only PMMR and only autopsy demonstrated equal rates (p-value = 0.5846).

Radiological Analysis

We analyzed PMCT scan data (15-25, 27). The scan parameters evaluated were as follows: row, scan sample, reconstruction, kernel, slice thickness, kVp, and mAs (Table 5.a). A lack of uniformity in the protocol application was observed. The row apparatus most used was the 128-scanner with a 3D reconstruction. The various scan protocols involved the use of the following parameters in most cases: 120 kV; the hard kernel for the reconstruction of bone setting and the soft kernel for the soft tissues. There was extreme variability in the other parameters, such as mAs and slice thickness.

Four articles (12, 13, 17, 19) acquired scans on the larynx using micro-TC and described the apparatus and voxel size. Three studies (12, 13, 17) indicated the kV, micro-amperage, and time of exposure, and one (13) described filtration (Table 5.b).

Five articles (16, 24-27) performed laryngeal PMMR: two (15, 25) with a 3T scanner and three (24, 26, 27) with a 1.5T scanner. T1, T2, and STIR sequences were performed in all studies, and FLAIR in only one (25). Four studies (15, 24, 25, 27) employed a slice thickness of 3 mm, two (24, 27) of 3, 4, and 5 mm, and one (26) did not describe it (Table 5.b).

Discussion

Laryngohyoid injuries occur because of biomechanical mechanisms, due to direct trauma, with the application of a high kinetic energy/force, or indirect trauma, with a kickback mechanism causing contrecoup injuries; muscular contractions can even cause bone fractures (28, 29, 30). Several factors influence the formation mechanism of hyoid bone fractures, such as its different morphology, application site, direction of the force, cancellous bone structure, cortical thickness, ossification of the bone density of the body–great horn junction, the hyoid bone, and ankylosis of the great or small horns (31-34). The development of fractures in the larynx is also influenced by several factors, such as its degree of ossification and morphology (frail, intermediate, or robust) (1, 35, 36). In addition, the anatomical position of these organs influences their damage.

According to these considerations, our study reveals that the investigated hyoid and thyroid cartilage fractures were most likely accident-related; we can assume that this depends on the high-energy trauma that characterizes acci-

Table 5a: PMCT scan parameters

Articles	Row apparatus	Sample scan	Reconstruction	Kemel	Slice thickness (mm)	KVP	MAS
De Bakker H. M. et al 2020 (15)	32 - 64	hyoid - larynx	3D	soft - hard	0.5 - 1	120	350
Deininger-Czermak E. et al 2020 (16)	128 row	whole body - head - neck	3D	NA	0.4 - 0.6	120	800
Thali M.J. et all 2003 (27)	NA	whole body - extremities	2D - 3D	NA	5 - 1.25	NA	NA
Yen K. et al 2005 (24)	NA	head - neck	2D - 3D	NA	1.5	NA	NA
Kempter M. et al 2009 (18)	6	neck	2 D - 3D	NA	1.25 - 1.5	NA	NA
Le Blanc-Louvry I. et al 2013 (20)	64	whole body	3D	soft - hard	0.625 - 1.25 - 2.5	120	200
Maiese A. et al 2014 (21)	NA	NA	3D	NA	NA	NA	NA
Polacco M. et al 2013 (22)	16	whole body	2D - 3D	10-30-40-70-80	0.75	140	160 - 180
Schulze K. et al 2018 (23)	128	whole body	3D	soft - hard	0.6	120	800
Kettner M. et al 2014 (19)	128	larynx	3D	NA	0.6	120 - 140	NA
Deininger-Czermak E. et al 2020 (25)	128	head - neck - thorax - abdomen	3D	soft - hard	0.2 - 0.3 - 0.4 - 0.6	120	400
Fais P. et al 2016 (17)	*64*	*larynx*	*3D*	*NA*	*2*	*120*	*36*

Table 5b: micro-CT and MRI scan parameters

MICRO-CT

Articles	Apparatus	Sample scan	kV	Current μ	Filtration	Voxel size μm	Exposure (ms)
Baier M. et al 2019 (13)	Nikon xt 225 320 Lc	larynx	80 - 150	718 - 73	0.35 mm copper	57.5 - 79.7	708 - 500
Baier M. et al 2020 (12)	Nikon xt 225 320 Lc	larynx	120	135	NONE	40	500
Kettner M. et al 2014 (19)	DRZ plus scintillator Y.CT	larynx	NA	NA	NA	46 - 61 - 65	NA
Fais P. et al 2016 (17)	Skyscan 1172 HR	larynx	65	153	NA	15	1210

MRI

Articles	Tesla	Sequences	Slice thickness (mm)	Orientation
Yen K. et al 2005 (24)	1.5	T1 - T2 - T2 Fat Sat - STIR	2- 3 - 4 - 5	Transverse - Coronal
Deininger-Czermak E. et al 2020 (16)	3	T1-T2-STIR	3	Transverse
Deininger-Czermak E. et al 2020 (25)	3	T1-T2-STIR-FLAIR	3	Transverse - Sagittal
Duband S. et al 2009 (26)	1.5	T1-T2-STIR	NA	Sagittal
Thali M.J. et al 2003 (27)	1.5	T1-T2-STIR	01-mag	Sagittal - Coronal

NA: not available; D: dimensional.

dents. In suicides, there was a similar percentage of hyoid bone and thyroid cartilage fractures (41% vs. 48%). We can assume that this is related to the high prevalence of hanging among suicide types, with a prevalent involvement of the hyoid bone, which is different from homicides (29, 30). Concerning homicides, thyroid cartilage lesions occurred in twice as many cases compared to hyoid bone injuries. We can hypothesize that this is also related to the application of direct force on the neck; thyroid cartilage is more exposed to direct trauma because of its anatomical position.

Laryngohyoid injuries, unfortunately, sometimes remain inconclusive when performing only one diagnostic method dependent on the presence of micro-fractures or the complex anatomical relationship of neck organs and their anthropometric morphological variability (21, 37).

Radiological investigations are fundamental in some types of deaths, especially in those characterized by non-specific autoptic or macroscopically non-identifiable signs, such as the gas bubble sign (5); this supports the work of pathologists featuring high sensibility (79.2%) and specificity (90.9%). PMCT is capable of detecting cervical column injuries, as well as hyoid and thyroid fractures, when combined with conventional autopsy (21). Micro-CT is an interesting radiological procedure, although still underutilized and not yet considered an alternative to histopathology (12). Some authors proposed to perform a micro-CT scan in the case of decomposed bodies or small structural abnormalities of neck organs, such as dislocations (19). Autopsy, on the contrary, also achieves better results in the identification of neck soft tissue hemorrhages (22). One study reaffirmed that histological analysis remains the gold standard in the case of suspected fractures (15). Another found that PMCT and autopsy have equal effectiveness (5). One encouraged the integration of autopsy with radiological investigations to better define the inconclusive lesions (20). Our study shows results similar to this last observation, demonstrating that autopsy cannot be replaced by postmortem radiology for a better diagnosis performance (38, 39) and remains the gold standard in the diagnosis of laryngohyoid and soft tissue lesions. Nevertheless, the combined approach using autopsy in association with radiological techniques obtained the best results, demonstrating the utility of the multidisciplinary approach to significantly reduce the number of unidentified lesions.

In the context of radiological analysis, great variability in the radiological scan parameters has emerged, although larynx PMCT protocols exist (40). We are in need of a general postmortem radiological protocol, which could influence the diagnosis.

Conclusion

Although autopsy remains the main diagnostic instrument in the diagnosis of laryngohyoid injuries and is not replaceable by radiology, it should be combined with radiological techniques in the diagnosis of neck lesions to significantly reduce the number of unidentified lesions. This study identified the significant differences between homicides, suicides, and accidents regarding lesions. It also highlighted the different results of each diagnostic method, providing guidance in the choosing of a diagnostic process. This analysis encourages the use of a multidisciplinary approach in the context of the diagnosis of laryngohyoid injuries. In addition, it therefore encourages the drafting of guidelines for radiological scans of the laryngohyoid complex.

Study Limitations

The analyzed studies did not report data regarding the specific deaths in the context of homicides, suicides, and accidents. For this reason, we performed a transversal analysis regarding homicides, suicides, and accidents in general, not taking into account the specific kind of death in each subgroup; it would make this study too dispersive. Some studies did not analyze all parameters taken into account in our study. There are currently few available studies comparing autopsy and radiological techniques in the diagnosis of laryngohyoid injuries. There are no blinded studies. The radiological analysis was incomplete because of the variability or absence of information on scan protocols.

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Abbreviations:
- PMMR: post- mortem magnetic resonance;
- MRI: magnetic resonance imaging;
- PMCT: post mortem computed tomography;
- PMFP: post-mortem fine preparation;
- IC: confidence intervals;
- R: right;
- L: left.

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