Are three-dimensional airway evaluations obtained through computed and cone-beam computed tomography scans predictable from lateral cephalograms?

A systematic review of evidence

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ABSTRACT

Objective: To systematically review the literature correlating upper airway parameters between lateral cephalograms (LC) and cone-beam computed tomography (CBCT) or computed tomography (CT) scans to determine the utility of using LC to predict three-dimensional airway parameters.

Materials and Methods: Both electronic and manual searches of the included studies were performed by two reviewers, and the quality of the studies that met selection criteria were assessed.

Results: A total of 11 studies from the literature met the selection criteria. Assessed outcome variables showed correlation r < .7 between the LC and CT scans. The correlation between the LC and CBCT ranged from weak to strong with $-.78 \le r$ and $r \le .93$ reported in the nasopharyngeal segment. In the oropharyngeal segment, a weak to strong correlation was reported with a range of $-37 \le r$ and $r \le .83$ between the CBCT and LC. All associations in the hypopharyngeal segment showed a weak correlation. Four of studies were of weak quality, five were of moderate quality, and two were rated to be of strong quality.

Conclusion: No strong correlations were reported between the LC and CT scans. However, the LC-derived adenoid-nasopharyngeal ratio and the linear measurement (posterior nasal spine, PNS, to posterior pharyngeal wall) had a strong correlation with upright nasopharyngeal area and volume in the CBCTs. The area measurement in conventional LC can be also used as an initial screening tool to predict the upright three-dimensional oropharyngeal volumetric data. The variability of the hypopharyngeal segment cannot be predicted by LCs. However, more well-designed studies are needed to determine the clinical utility of using LC to predict airway size. (*Angle Orthod.* 2017;87:159–167)

KEY WORDS: Cone beam computed tomography; Lateral cephalograms; Systematic review; Upper airway

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INTRODUCTION

Various diagnostic tools such as questioners, endoscopy, the Mueller Maneuver, static radiologic imaging, dynamic scanning, and polysomonography are used for airway evaluation. Polysomonography is deemed as the gold standard test for diagnosing obstructive sleep apnea (OSA).¹ However, it does not provide clinicians with anatomical information to guide

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therapy. Endoscopy may be used clinically to evaluate the site of airway collapse, but it is not able to evaluate the submucosal and deeper airway morphology and is subjective. Imaging modalities are adjunctive to physical examination and craniofacial characteristics and have been correlated with the severity of airway obstruction. The lateral cephalogram (LC) is considered a standard tool for maxillofacial surgeons to predict treatment interventions and quantify the changes of airway structure before and after the use of mandibular advancement devices or maxillomandibular advancement surgery treatments.^{1,2}

LC generates two-dimensional (2D) images of a three-dimensional (3D) structure and suffers from distortion, magnification, lack of transverse dimensions, and superimposition of bilateral craniofacial structures,^{3,4} which render an inadequate size and a complexity of airway structure assessments. However, LC measurements provide the ability to differentiate between OSA and non-OSA patients and have been correlated with the severity of the disorder. Increasing in upper airway length, narrowing of the nasopharynx and oropharynx, and enlargement of the soft tissue in the upper airway can be correlated with the presence and severity of OSA.^{5,6}

Computed tomography (CT) provides the ability to evaluate the hard and soft structures of the airway in 3D.⁷ Anatomic measurements such as the retropalatal space and the lateral anteroposterior diameter are correlated with the severity of OSA.^{8,9} CT scanning notably enhances soft tissue contrast along with 3D assessment, which allows precise measurements at different airway levels. In addition, CT dynamic scans allow the study of the airway structure changes during respiration and sleep cycling, which can play important roles in evaluating and managing OSA patients. However, high radiation dose exposure (especially for younger people) and high financial costs are considered the main CT scan limitations.^{1,10,11}

Cone beam computed tomography (CBCT) successfully represents the true 3D morphology of the head and neck structures in the upright position. A CBCT's ability to discriminate borders of soft tissue structure and void spaces makes it a valid and reliable diagnostic modality to analyze static airway structure.¹² Ogawa et al.¹³ have shown a relationship between the airway volume and minimum cross-sectional area in patients with and without OSA. OSA patients presented with less anterior posterior airway dimension, less minimum cross-sectional area, and lower airway volume.

We hypothesize that because the upper airway has a spherical or elliptical shape,^{13,14} the linear measurements from 2D images may predict the cross-sectional area and volume of the airway with a significantly

Table 1.	Key Words	s Based on	Databases in	Details
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PubMed	
(("Cone-Beam Computed Tomography"[Mesh] OR cone beam computed tomography OR CBCT OR "Tomography, X-Ray Computed"[Mesh] OR "computed tomography") AND ("Cephalometry"[Mesh] OR cephalogram OR cephalometric) AND (airway))	
Web of Science	
((cone beam computed tomography OR CBCT OR computed tomography) AND (cephalograms OR cephalometric OR cephalometry) AND (airway)) CINHAL (cumulative Index to Nursing and Allied Health Literature) ((cone beam computed tomography OR CBCT OR computed tomography) AND ((MM "Cephalometry") OR cephalogram OR cephalometric) AND (airway))	
cone beam computed tomography OR CBCT OR computed tomography) AND (cephalograms OR cephalometric OR cephalometry) AND (airway)	

smaller dose of radiation exposure than 3D imaging modalities. However, to the best of our knowledge, no reported systematic review is available on the correlation between CBCT/CT and LC airway assessment.

The aim of the present study is to systematically review the literature correlating upper airway measurements from LCs to measurements from CBCT/CT scans. This will help determine the possible utility of LCs as a valid screening tool to estimate airway size to predict OSA risk and quantify the response to surgical intervention.

MATERIALS AND METHODS

Focus Question

The focus question is the following: Are 3D airway measurements obtained through CBCT and CT scans associated with LC variables?

Review Protocol

A comprehensive electronic search through PubMed, Cumulative Index to Nursing and Allied Health Literature (CINHAL), Web of Science, and Science Direct databases up to November 8, 2015, was conducted. Table 1 summarizes the final search keywords for each database in detail. A manual search of the reference lists of the included studies was performed to supplement the literature search. Furthermore, to improve the reporting of the current systematic review, Preferred Reporting Items for Systematic Reviews and Meta-Analyses statement guidelines were followed.

Inclusion and Exclusion Criteria

The Population, Intervention, Comparison, and Outcome framework was followed to improve search

strategy. The population was defined as the patients who have both CBCT/CT scans and CT generated, CBCT generated, or conventional LCs for airway analysis. The intervention was defined as the CBCT or CT imaging, and the comparison was defined as conventional LCs, or CBCT-generated LCs, or CTgenerated LCs. The outcome was described as similarity or correlation of linear, surface area, volume measurements, and any other cephalometric variables that compared between the CBCT/CT scans and LCs in airway analysis.

Excluded were the studies that were case reports, reviews, editorials, commentaries, unpublished studies, conference proceedings, and theses; were not available in English; or had a small sample size (n < 5).

Data Extraction

Data extraction was independently performed by two reviewers. Any discrepancies were solved by discussion and consensus. When assessing the correlation, the following classification was used: no or very weak correlation when $r \le .3$, weak correlation when $.3 < r \le .50$, moderate correlation when $.50 < r \le .70$, and strong correlation when $.70 < r \le 1.^{15}$

Quality Assessment

van Vlijmen¹⁶ performed a systematic of review in 2012 to evaluate what level of evidence is available to reinforce the use of CBCT in orthodontic diagnosis and treatment planning. They developed a scoring system based on Lagravere and Gordons's scoring systems.¹⁷ The scoring system of van Vlijmen's study was adapted for all study designs that evaluated 12 criteria. We adapted the scoring system by removing the randomization item because the studies did not apply a real intervention and are scored using the remaining criteria (Table 2).

The results and mean quality (mQ) were reported and interpreted by percentage as follows: mQ < 60% = poor quality, $60\% \le mQ < 70\%$ = moderate quality, mQ $\ge 70\%$ = good quality. Finally, any disagreement was settled by discussion and consensus.

RESULTS

Articles

A total of 619 articles were found in the initial review. No study was included through manual search. Of these articles, 18 were considered potentially eligible after title and abstract screening. Upon consultation of the full texts, consequently, 11^{18–28} of 18 studies met all the inclusion criteria (Figure 1). Table 3 presents the demographic characteristics of the included studies.

Table 2.	Methodological	Scoring
	Methodological	oconing

I. Study design (total = 6; response ^a : \checkmark , o)	
A. Objective—objective clearly formulated	
B. Sample size—considered adequate (n \geq 30)	
C. Sample size—estimated before collection of c	lata
D. Selection criteria—clearly described	
E. Baseline characteristics—similar baseline cha	racteristics
II. Study measurements (total = 3; response: \checkmark , o,	NA)
G. Measurement method—appropriate to the obj	ective
H. Masked measurement method—masking	
I. Reliability—adequate level of agreement	
III. Statistical analysis (total = 4; response: ✓, o, N	A)
J. Statistical analysis—appropriate for data	
K. Confounders-confounders included in analys	sis
L. Statistical significance level—P value stated	

L. Statistical significance level—

M. Confidence intervals provided

 $^{\rm a}$ $\checkmark,\,$ Fulfills satisfactorily the methodological criteria; o, does not fulfill the methodological criteria or is not clarified; NA, not applicable.

Various borders have been applied among studies to define the airway segments. Therefore, in the present review, the segments were considered to be on the topic of nasopharyngeal, oropharyngeal, velopharynx, and hypopharyngeal spaces as determined by the authors.

CT scans – *LC* correlation. Of the 11 studies, 4 investigated the correlation between CT (supine)/ LCs.^{18–21} All measurements were reported as none, weak, or moderate correlations, $.70 \le r \le .70$ (Table 4).

CBCT scans – *LC* correlation. Of the 11 studies, 7 evaluated the correlation between the LCs and CBCT (upright) scans in the different segments (Table 5).^{22–28}

Nasopharyngeal segment. A weak to strong correlation with a wide range of correlation coefficients was reported between LCs and CBCTs.^{23–28} The adenoidal–nasaopharyngeal ratio in conventional LCs has a negative strong correlation with nasopharyngeal volume in CBCT (r = -.78).²³ Similarly, the linear measurement of PNS to the posterior pharyngeal wall in conventional LCs can predict the nasopharyngeal area (r = .81).²⁴ Moreover, ad2-PNS (upper sagittal depth of the nasopharyngeal airway) in CBCT orthogonal-generated cephalograms can strongly predict the nasopharyngeal volume (r = .93).²⁶

Oropharyngeal segment. A strong correlation (r = .71) was reported between the linear measurements in CBCT-generated cephalograms and area measurements in CBCT scans.²⁶ Also, a strong correlation (r = .83) exists between the area measurement of conventional LCs and the volume measurements of CBCT scans.²² Figure 2 illustrates the strongly correlated measurements.

Hypopharyngeal segment. Weak correlations were observed between LC and CBCT.²⁵



Figure 1. Flow diagram.

Quality Assessment

Of the studies, 4 were of weak quality,^{18,19,24,27} 5 were of moderate quality,^{21–23,25,28} and 2 were rated to be of strong quality.^{20,26} Most of the included studies suffered from a lack of sample size estimation before data collection, selection bias, and lack of reporting confidence intervals (Table 6).

DISCUSSION

The present review reveals that there is no strong correlation between LCs in an upright position and CT scans in a supine position. The results may be a result of the dimensional changes in airway that occurs between the supine and upright positions of the patients.²⁹⁻³¹ CT and CBCT scans have been introduced to study the 3D airway structure. However, the

effective doses of CT (429.7 μ Sv) and CBCT (56.2–61.1 μ Sv) imaging are markedly greater than LCs (10.4 μ Sv),^{32,33} and their long-term effects have still remained unknown.

LC provides static imaging of a dynamic structure, whereas ultrafast CT scanning allows a dynamic evaluation of the airway during respiratory cycles. Of the included studies, Yucel et al. compared dynamic CT imaging with static LC radiographs, which may have contributed to the poor correlation between the modalities.²⁰

In nasopharyngeal segments, no statistically significant difference was found between CBCT scans and conventional LCs in linear measurements.²⁴ Some studies reported a strong correlation between the CBCT and LCs.^{23,24,28} However, Aboudara et al.²⁸ used the axial CBCT reconstruction plane passing through

3 ^a

Author Voor	CBCT/CT Imaging	Sampla Sizo/Aga	Imaging Parameters	Turpo of LC	Patient Position	Number of
Author, Year	Systems	Sample Size/Age				Observers
Bronoosh ²² 2015	CBCT NewTom VGi	35 patients/21.7 years \pm 2.6	FOV: 15 in 15	Con	Upright	1
Feng ²³ 2015	CBCT 3D-exam Kavo	55 patients/32: ≤15 years 23: >15 years	kV: 120 mA: 5 VS: 0.2 Time: 14.7 seconds	Con	Upright	2
Vizzotto ²⁴ 2012	CBCT i-CAT	30 patients/mean 17.5 years	mA: 3–8 kVp: 120 Focal spot: 0.5 mm FOV: 13 cm VS: 0.25 mm ³	Con	Upright	2
Sears ²⁵ 2011	CBCT MercuRay	20 patients (56 cases)/23.85 years (14–43)	FOV: 12 in kVp: 100 mA: 2 Time: 9.6 seconds	Con	Upright	1
Kim ²⁷ 2010	CBCT Master 3D	27 patients/11.19 years \pm 1.28	FOV: 12 in Thickness: 0.3 mm	CBCT generated	Upright	
Lenza ²⁶ 2010	_	34 patients/18 years \pm 11 (11–56)	VS: 0.36	CBCT generated	Upright	2
Abramson ¹⁸ 2010	СТ	15 patients		Con	Supine	1
Aboudara ²⁸ 2009	CBCT NewTom-9000	35 patients/14 years ± 2 years 2 months	kV: 110 mA: 15 Time: 18 seconds	Con	Supine	
Olszewska ¹⁹ 2008	Static CT	28 patients/43-65 years	_	Con	Supine	1
Yucel²⁰ 2005	Dynamic CT	47 patients/49 ± 7.8 years (20–64 years)	kV: 120 mA: 50 thickness, 5 mm; Scan time: 1 seconds FOV: 400 mm	CT generated	Supine	1
Lam ²¹ 2004	Static CT	92 patients/Normal = 41.5 ± 6.4 years OSA = 46.4 ± 8.5 years	Scan time: 5 seconds	CT generated	Supine	1

^a CBCT indicates cone-beam computed tomography; CT, computed tomography; LC, lateral cephalometry; NS, nonsignificant difference; NR, not reported; VS, voxel size; Con, conventional; FOV, field of view; LR, lateral reconstruction; OSA, obstructive sleep apnea.

PNS as one of the boundaries for the nasopharyngeal area in LCs, which may overestimate the actual efficiency of LCs.

In orthogonally generate LCs from CBCT scans, a strong correlation was reported between linear (LC) and volume (CBCT) measurement, which is in disagreement with the Sears et al.²⁵ study, which reported

a weak correlation between CBCT and conventional LCs. The discrepancy may have arisen because orthogonal CBCT projections are more accurate than conventional LC in the midsagittal dimensions.³⁴ However, using the same exposure to generate both images, eliminating the variation in airway size because of function, may explain the higher correla-

Table 4. Summary of Results for CT or LC Correlations

Author	Outcome Variables ^a	Results			
Abramson 2010	LC linear/CT area and volume: oro	CC: no correlation			
	Intraobserver reliability	LC: 0.84–0.99 (P < .001)			
		CT: 0.86–1 (P < .001)			
	Interobserver reliability	LC: 0.91–0.99 (P < .001)			
		CT: 0.89–1 (P < .001)			
Olszewska ¹⁹ 2008	1-LC linear/CT linear: naso, oro, and hypo	CC: all parameters correlated < 0.7			
	2-LC area/CT area (nasal airway)	r < .2			
Yucel ²⁰ 2005	LC linear/CT area	CC: all parameters correlated <0.5			
Lam ²¹ 2004	LC linear/CT area	CC: all parameters had no or weak correlation			

^a CT indicates computed tomography; LC, lateral cephalometry; CC, correlation coefficient; naso, nasopharynx; oro, oropharynx; hypo, hypopharyngeal.

Author	Outcome Variables ^a	Results
Bronoosh ²² 2015	LC area/CBCT volume: oro	CC: <i>r</i> = .83
Feng ²³ 2015	Adenoidal nasopharyngeal ratio on LC and Nasopharyngeal	CC:
	volume on CBCT	Age < 15:-0.78
		Age $> 15; -0.57$
	Adenoidal nasopharyngeal ratio on LC and total airway volume	Age < 15 $r = -48$
	on CBCT	$A_{00} > 15 r = -32$
	Observer agreement	$\frac{1}{10} = \frac{1}{10} $
	observer agreement	
		Interchanner CC:
		ANR: 0.96-0.89
		NP volume: 0.96–0.97
Vizzotto ²⁴ 2012	1. Similarity of CBCT lateral, CBCT axial cut, and LC linear	1. means
	Naso	Naso: all NS
	Oro	Oro: significant just for LC vs CBCT axial cut
	2. LC linear/CBCT area	2. CC:
	Naso	<i>r</i> = .81
	Oro	r = .52 (P < .001)
Sears ²⁵ 2011	LC linear/CBCT volume	CC:
	Naso	r = .43 (P < .001)
	Oro	r = .49 (P < .001)
	Нуро	r = .16 (P < .26)
	Interrater reliability: LC vs CBCT	r = .95 vs .88
	Naso	r = 60 vs 97
	Oro	r = 98 vs 79
	Hypo	NSD only for LC in oro segment
Kim ²⁷ 2010	Lateral conhalometric linear variables (Conial angle AEH	
1111 2010	DEL DEL/AEL EMA Dt A to N porp. Dog to N porp. ANR. Mp body	00.
	Friterin/Arti, riva, rt A to N peip, rog to N peip, AND, wit body,	
		runned from 14 to 00
	Naso	r ranged from 14 to .39
		r ranged from 37 to $.41$
	l otal airway	r ranged from 42 to .66
Lenza ²⁶ 2010	1. LC linear/CBCT area	
	Naso	/ _
	ad1-PNS	$r = .79 \ (P = .00)$
	ad2-PNS	<i>r</i> = .93
		(P = .02)
	Oro (velopharynx)	
	Phw2-Tb	$r = .47 \ (P = .05)$
	T2-P3	$r = .27 \ (P = .12)$
	P'-P	$r =02 \ (P = .91)$
	E1-E2	$r = .71 \ (P = .00)$
	2. LC linear/CBCT volume	
	Naso	<i>r</i> = .93
	Upper velopharynx	<i>r</i> = .37
	Lower velopharvnx	<i>r</i> =10
	Upper oropharynx	<i>r</i> = .11
	Total airway	r = .58
Aboudara ²⁸ 2009	L C area/CBCT volume	CC
	Naso	r = 75 P < 001
		Airway volume more variability than area

Table 5. Summary of Results for CBCT and LC Correlations

^a CBCT indicates cone-beam computed tomography; LC, lateral cephalometry; CC, correlation coefficient; naso, nasopharynx; oro, oropharynx; hypo, hypopharyngeal, LR, lateral reconstruction of the CBCT images; NS, not significant; ANR, adenoidal nasopharyngeal ration; NP, nasopharynx.

tion. In other words, the difference between the LC and the CBCT observed in the Sears et al.²⁵ study might be a result of the difference in tongue position or swallowing rather than a difference resulting from the imaging technique. However, despite the high correlation found between CBCT imaging and LCs in nasopharyngeal segment assessment, LCs are not always accurate. These 2D radiographic images have limitations in displaying the posterior nasopharyngeal airway,³⁵ wide airways, and turbinate protuberance.²⁸ Therefore, using a 3D analysis might be beneficial for such assessments.



Figure 2. Conventional lateral cephalograms measurements show strong correlation with cone-beam computed tomography (CBCT). (A) Adenoidal nasopharyngeal ratio correlated with volume of nasopharyngeal. (B) Area measurement boundaries (the superior border: the edge of the hard palate to the posterior of the pharynx (extension of ANS to PNS); The inferior border: the tip of the epiglottis (on a plane parallel to the superior edge) correlated with CBCT volumetric data. (C) Linear measurement (PNS to the posterior pharyngeal wall) correlated with CBCT area measurement.

The oropharynx is deemed as the most common site of upper airway collapse in adults with OSA.³⁶ Thus, anatomic evaluation of this region is of critical importance. Lenza et al.26 and Bronoosh et al.22 reported a strong correlation between the CBCT scans and LCs. Yet, no strong correlation was found within the other included studies between the CBCT and LC measurements ($r \leq .52$) in the velopharyngeal segments.²⁶ The weak correlation in these regions can be explained by the fact that the airway is not spherical except for the nasopharyngeal segment. Moreover, CBCT scans show moderate level of interobserver reliability in linear width, cross-sectional area at the level of the vallecula, and minimum axial area (r =.66).³⁷ Landmarks with lower densities have also a high measurement error in 2D radiographs and 3D imaging. $^{\rm 38,39}$ However, CBCT images provide more precise soft tissue and hard tissue landmark identification than LCs. $^{\rm 40}$

In the hypopharyngeal area, very limited studies have been performed. However, poor correlation exists in this region between the 2D and 3D modalities.^{21,25} Poor landmark identification and high superimposition in 2D radiographs can again contribute to the weak correlation between 2D and 3D imaging in this region. In addition, no strong association reported between the total volume of airway obtained through CBCT and LC linear/area measurements. This poor correlation is contributed to dramatic differences in airway shape that exist in the oropharyngeal and hypopharyngeal spaces.¹⁴

The present study reveals the higher correlations for upright CBCT and upright LC than supine CT and upright LC imaging, which may be explained by positional changes in the airway. Reductions in airway antero-posterior dimensions and cross-sectional area have been demonstrated in the supine posture. Furthermore, increasing in the thickness of the soft palate and tongue in the cross-sectional area and increasing in the posterior tongue pressure have been shown in a supine airway position.^{29,30,41} In comparison between CT scans in supine position and CBCT scans in sitting upright position, the soft palate, epiglottis, and entrance of the esophagus have a caudal movement when the posture changed from supine to sitting upright and a posterior movement from an upright to a supine position. Hyoid bone caudal movement as a result of postural changes has also been demonstrated.31

Lack of control over the confounding factors may justify the inconsistent results. The CBCT scans and LCs ideally should be taken at the same time for accurate comparison, and some included studies did not take this into account.^{18,19,25,28} Using the same

Table 6. Methodological Quality Scores for Study Measurements

	Methodological Score ^a												
Authors, Year	Study Design				Study Measurement		Statistical Analysis						
	А	В	С	D	Е	G	Н	I	J	К	L	М	Average Score, %
Feng ²³ 2015	1	1	0	1	1	1	1	1	0	1	0	0	66.6
Bronoosh ²² 2015	1	1	0	1	1	1	0	0	1	1	1	0	66.6
Lenza ²⁶ 2010	1	1	0	1	1	1	1	1	1	1	1	0	83.3
Kim ²⁷ 2010	0	1	0	1	1	1	0	0	1	1	1	0	58.3
Olszewska ¹⁹ 2008	0	0	0	1	1	1	0	0	0	0	1	1	41.6
Yucel ²⁰ 2005	1	1	0	1	1	1	1	0	1	1	1	0	75.0
Lam ²¹ 2004	1	1	0	0	0	1	1	0	1	1	1	1	66.6
Vizzotto ²⁴ 2012	1	1	0	1	0	1	1	0	1	0	1	0	58.3
Sears ²⁵ 2011	1	1	0	1	1	1	0	1	1	0	1	0	66.6
Aboudara ²⁸ 2009	1	1	0	1	1	0	0	1	1	1	1	0	66.6
Abramson ¹⁸ 2010	1	0	0	0	0	1	1	1	1	1	1	0	58.3

^a \checkmark : Fulfills satisfactorily the methodological criteria. o: Does not fulfill the methodological criteria or is not clarified.

head positions, tongue positions, techniques, and imaging devices are also essential to reach conclusive results.^{42,43} Furthermore, imaging at the different stages of respiration and swallowing cycles between CBCT/CT and LCs may also affect the airway size. During expiration, the airway size at all anatomic segments was significantly larger than inspiration.⁴⁴ In addition, another limitation in the data synthesis of the present review is the various borders that have been defined across the studies. Various anatomic landmarks have been used to border the nasopharyngeal, oropharyngeal, and hypopharyngeal segments, which may justify why some values do not correlate between the studies. However, very close anatomic landmarks have been applied across the most of studies, which may minimize the influence of this confounding factor. (Please contact the authors directly to receive the applied borders in depth within each study.)

Based on the evaluation of the analytical approach section and the presentation of results, it appears that the included studies used Pearson correlation coefficients. However, only a few presented the actual scatterplots of data distribution. Although the appropriate statistical tests seem to have been used, the influence of outliers is unclear. We are then unable to accurately assess if the underlying assumptions (especially data distribution) regarding the use of parametric tests (in this case, Pearson correlation coefficients) were adequately satisfied.

CONCLUSION

- No LC measurements were found to strongly correlate with supine 3D airway measurements obtained thorough CT scans.
- The adenoid nasopharyngeal ratio and the linear measurement from PNS to the posterior pharyngeal wall parallel to floor on conventional LC can be used as the initial screening measurements to respectively estimate the volume and area of the nasopharyngeal upright measurements obtained from CBCT scans.
- The oropharyngeal area measurement from conventional LC can be used as an initial screening measurement to predict the upright upper airway 3D volume.
- Linear measurements of the hypopharyngeal segment from LCs cannot explain most of the variability in the volumetric measurements from CBCT scans.
- CBCT volumetric airway measurements correlated better with airway measurements from CBCT-generated LC than conventional LC. This is likely a result of the fact that the CBCT-generated LC originates from the same exposure as the 3D CBCT image with the muscles surrounding the airway in the same functional position.

• The results of the included studies in this systematic review should be interpreted with caution because the observer reliability, regression analysis scatterplot, and impact of outliers on the correlation were not reported within some of the included studies.

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