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Volumetric measurement of the tongue and oral cavity with cone-beam computed tomography: A systematic review

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ABSTRACT

Purpose: The goal of this systematic review was to compare the use of cone-beam computed tomography (CBCT) with that of computed tomography (CT) for volumetric evaluations of the tongue and oral cavity.
Materials and Methods: A search for articles was conducted in accordance with the Preferred Reporting Items for Systematic Review and Meta-analyses guidelines. The PubMed, Scopus, ScienceDirect, and SAGE Journals databases were searched for articles published between 2011 and 2021. Articles were screened and assessed for eligibility. Screening involved checking for duplication, reading the title and abstract, and reading the full text.
Results: The initial search retrieved 25,780 articles. Application of the eligibility criteria yielded 16 articles for qualitative analysis. Multiple uses of CBCT were identified. In several studies, researchers assessed the volumetric correlation between tongue and oral cavity volumes, as well as other parameters. Post-treatment volumetric evaluations of the oral cavity were also reported, and the reliability of CBCT was assessed. The use of CT resembled that of CBCT.
Conclusion: CBCT has been used in the evaluation of tongue and oral cavity volumes to assess correlations between those volumes and with the upper airway. It has also been used for volumetric evaluation after surgical and non-surgical procedures and to assess the relationships between tongue volume, tooth position, occlusion, and body mass index. Participants with obstructive sleep apnea and malocclusion have been evaluated, and the reliability of CBCT has been assessed. In the included studies, CT was utilized for similar purposes as CBCT, but its reliability was not assessed. ***(Imaging Sci Dent 2022; 52: 333-42)***

KEY WORDS: Tongue; Mouth; Organ Size; Cone-Beam Computed Tomography

Introduction

The oral cavity has a complex anatomy and soft tissue functionality along with ill-defined boundaries, making its volumetric imaging technically difficult.[1] Various methods have been used to measure the volumes of the tongue and oral cavity, including conventional imaging, 2-dimensional imaging, and 3-dimensional imaging.[1] Studies conducted by Bandy and Hunter,[2] Oliver and Evans,[3] Sakakibara et al.,[4] Roehm,[5] and Lauder and Muhl[6] have described the measurement of tongue volume and oral cavity volume using methods such as measuring the volume of water displacement; making alginate impressions; and utilizing lateral cephalograms, computed tomography (CT), and magnetic resonance imaging (MRI). However, Cohen and Vig,[7] Sutthiprapaporn et al.,[8] and Macovski[9] reported that these methods produced suboptimal imaging for evaluating the tongue and oral cavity volumes because they poorly represented the oral cavity and surrounding tissue structures, failed to show complex 3-dimensional variations, required a long exposure time, and affected the shape and volume of the tongue due to the influence of gravity. In short, previous methods used to measure the volumes of the tongue and the oral cavity produced suboptimal imaging due to their limitations in representing the morphological structure

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of the oral cavity.

Cone-beam computed tomography (CBCT) may be used for the morphological evaluation of the oral cavity because of its high image quality and much lower effective dose of radiation compared to alternatives.[10,11] Farman and Scarfe[12] found that CBCT had a shorter exposure time because the image projection was obtained in a single rotation; additionally, it minimized motion artifacts because the patient sits upright while the image is taken, preventing the tongue from falling backward. In essence, since it provided sub-millimeter resolution images of high diagnostic quality with a short scanning time and low radiation, CBCT was a promising alternative approach.[13] Therefore, CBCT showed promise for the evaluation of the morphological structure of the oral cavity because of its low effective radiation dose, short scanning time, and ability to produce optimal imaging through the minimization of motion artifacts due to gravity.

Notably, 3-dimensional CBCT has many clinical applications in dentistry, one of which is the volumetric evaluation of the tongue and oral cavity. Rana et al.[1] reported that the volume of the oral cavity, as well as the volume of the tongue, which was an important predictor of obstructive sleep apnea, may be related to the volume of the upper airway. Another study by Uysal et al.[14] used CBCT data to measure tongue volume and described its relationship with mandibular incisor irregularity. To summarize, oral cavity volume and tongue volume may be associated with upper airway volume and mandibular incisor irregularity.

Measuring the tongue and oral cavity volumes may be useful for estimating the degree of tongue enlargement in patients with macroglossia as a sign of Beckwith-Wiedemann syndrome or acromegaly, who often exhibit an anterior or lateral open bite.[15] These measurements could be used as part of a glossectomy treatment plan and to estimate the degree of tongue resection.[16] The reviewed studies highlighted several methods used to measure the volume of the tongue and oral cavity, including measuring the volume of water displacement; making alginate impressions; and utilizing lateral cephalograms, CT, or MRI, all of which produced suboptimal imaging.

In the present study, the use of CBCT was reviewed as a promising alternative in evaluating the volume of the tongue and oral cavity. CBCT has many advantages that compensate for its limitations in representing the morphological structure of the oral cavity. To the authors' knowledge, no study has reviewed the use of CBCT in evaluating the volumes of the tongue and oral cavity. This study was intended to examine the use of CBCT in the volumetric evaluation of the tongue and oral cavity compared to CT.

Materials and Methods

Research question

This systematic review was designed to compare the use of CBCT with that of CT in the evaluation of the volumes of the tongue and oral cavity.

Systematic review

This systematic review was conducted using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) protocol. The procedure was developed using the PRISMA checklist and has been submitted to the International Prospective Register of Systematic Reviews (submission number: 316381).

Search strategy

Three reviewers applied the eligibility criteria and selected studies for inclusion in the systematic review. Two main reviewers screened articles, while others checked the decisions made. Study selection was conducted from October 2021 to December 2021 using the PubMed, Scopus, ScienceDirect, and SAGE Journals databases with the keywords "tongue," "volume," "oral cavity," "cone-beam computed tomography," and "CBCT."

Inclusion and exclusion criteria

This review included articles that discussed the evaluation of tongue volume and/or oral cavity volume using CBCT or CT; included patients or participants whose tongue volume and/or oral cavity volume were evaluated; were written in English; had descriptive, cross-sectional, prospective, retrospective, or experimental study designs; were published within the last 10 years (2011-2021); and were available in full text. The exclusion criteria for this study were articles that included only an abstract, narrative review articles, and articles that did not discuss the method of processing CBCT images of the tongue and oral cavity volumes.

Data selection and charting

Two main reviewers screened the PubMed, Scopus, ScienceDirect, and SAGE Journals databases for relevant articles. Disagreements between reviewers were resolved by discussion and consensus. The first selection was made by screening for publication year. Duplication screening was performed by downloading all search results from each database in Research Information Systems format and exporting them to Mendeley (Elsevier, London, UK). Titles and abstracts were screened to assess the relevance of articles from the entire database. The remaining articles underwent a final screening involving reading the full text of the article; only studies discussing the evaluation of tongue and/or oral cavity volume via CBCT or CT were included in this systematic review. Twenty-three articles were not relevant. Information regarding the publication details (author, publication date) and details of each study was obtained. Data were managed in Excel (Microsoft, Redmond, WA, USA). Various uses of CBCT in evaluating tongue and oral cavity volumes were included in this review, with some uses of CT as supporting studies. The authors examined studies that discussed the evaluation of tongue volume and oral cavity volume with 3-dimensional imaging via CBCT. To comprehensively support the discussion, the authors also evaluated studies that discussed the reliability of CBCT. Other factors relevant to the evaluation of tongue and oral cavity volumes, such as upper airway volume, tooth alignment and occlusion, body mass index (BMI), tongue posture, and adaptation after surgical and non-surgical procedures, were discussed along with many other unique findings.

Quality assessment

Critical appraisal is the systematic evaluation and assessment of research regarding its validity, results, and relevance. The eligibility of articles generated from the screening process using the inclusion criteria was assessed using the Joanna Briggs Institute (JBI) critical appraisal tool. The JBI checklists for analytical cross-sectional studies (Fig. 1) and quasi-experimental studies (Fig. 2) consist of 8 and 9 scored questions, respectively. Potential responses include "yes," "no," "unclear," and "not applicable"; each criterion with a score of "yes" was assigned 1 point, and each with any other score was assigned no points. The total score of each study was then calculated. If the number of "yes" responses was above 50%, then the article was considered to be high quality. Articles were categorized as low-, medium-, and high-quality and were assessed by 3 researchers to reduce bias.

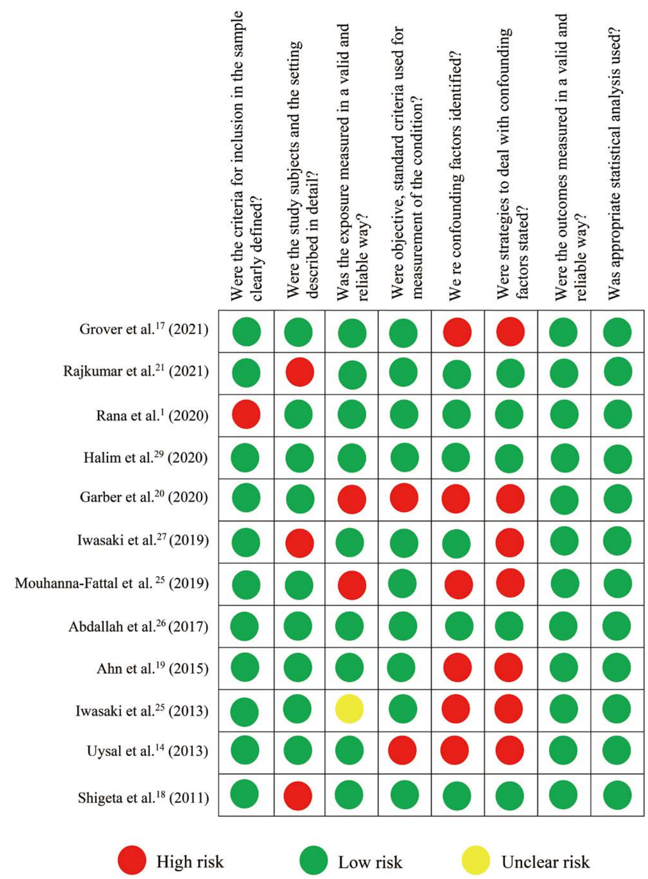

Fig. 1. Risk of bias assessment using the JBI critical appraisal checklist for analytical cross-sectional studies performed by 3 appraisers. JBI: Joanna Briggs Institute

Results

Identification of potential studies

The searches of the PubMed, Scopus, ScienceDirect, and SAGE Journals databases yielded a total of 25,780 articles; these were then screened for articles published in the last 10 years, resulting in 14,945 articles. The next selection involved removing 14,865 duplicate articles. Screening of titles and abstracts yielded 39 articles. All articles were available in full-text format. The full-text screening phase resulted in 16 potential articles relevant to the present systematic review. A flowchart is provided in Figure 3. A total of 16 articles were included and are listed chronologically in Table 1.

Characteristics of the included studies

Most peer-reviewed literature on the evaluation of tongue and/or oral volume were published recently. Early studies on the use of CBCT to measure tongue volume and/or oral cavity volume were carried out by Uysal et al.[14] and Iwasaki et al.[27] Most of the included studies (81.25%) were published in the last 5 years. A total of 56.25% of the studies were retrospective.

Risk of bias

A risk-of-bias assessment was performed on 16 studies using the JBI critical appraisal checklist. Twelve of these studies were assessed with the cross-sectional studies checklist; 11 were found to be of high quality, and only 1

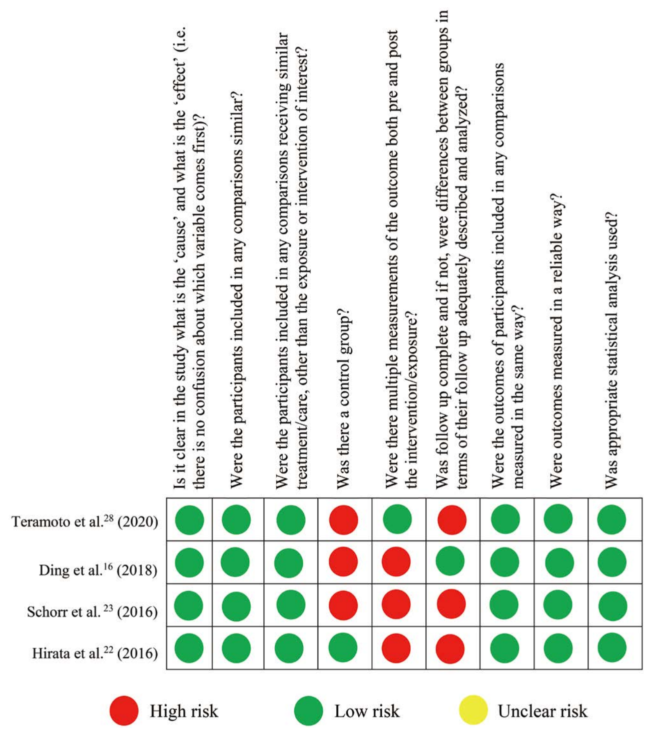

Fig. 2. Risk of bias assessment using the JBI critical appraisal checklist for quasi-experimental studies performed by 3 appraisers. JBI: Joanna Briggs Institute

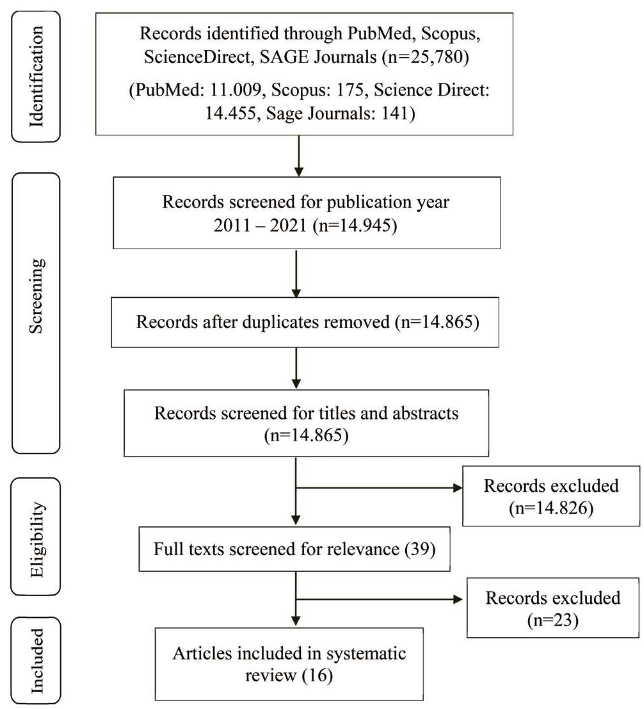

Fig. 3. Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) flowchart.

study was of moderate quality. The remaining 4 articles were quasi-experimental studies and were found to be of high quality.

Tongue volume and CBCT

Reviewed studies discussed the use of CBCT in the evaluation of tongue volume and the study of its relationship with mandibular incisor irregularities. The tongue played an indirect role in causing malocclusion; additionally, significant correlations existed between tongue volume and maxillary length, palatal vault depth, and interpremolar and intermolar width in the mandibular arch.[17] In another study, Uysal et al.[14] observed a higher tongue volume in patients with mild irregularities than in those with severe irregularities.

Oral cavity volume and CBCT

A study by Mouhanna-Fattal et al.[24] focused on the upper airway and craniofacial structure volumes in patients with obstructive sleep apnea. The results showed no significant difference in oral cavity volume between participants and controls. Another study, by Iwasaki et al.[25], focused on the impact of rapid maxillary expansion (RME) on tongue posture and pharyngeal airway volume in children with airway obstruction. The RME group showed a significantly reduced intraoral airway volume after treatment.

Tongue volume and oral cavity volume with CBCT

A study on class I malocclusion by Ding et al.[16] reported a significant correlation between tongue volume and oral cavity volume, but no significant relationship was observed between tongue volume and the volume of the oral cavity proper. Another study by Iwasaki et al.[27] examined class I, class II, and class III malocclusion and found similar findings, with a positive correlation between tongue volume and oral cavity volume. In patients with class III malocclusion, the tongue volume was greater than in class I and class II patients. The volume of the tongue/oral cavity was greater in class II patients than in class I patients. Studies by Rana et al.,[1] Ding et al.,[16] and Iwasaki et al.[27] on the volume of the tongue and oral cavity described a positive relationship between them. In cases of class III malocclusion, the volumetric ratio between the tongue and the oral cavity appeared to be maintained after orthognathic surgery.[28] The study by Rana et al.[1] on the ratio of tongue volume to oral cavity volume in the upper airway showed a significant negative correlation between the ratio of tongue volume to oral cavity volume and the volume of the oropharynx. Additionally, it showed that the tongue volume-to-oral cavity-

Table 1. Overview of included studies

Author	Study design	Imaging modality	Origin	Sample	Results
Shigeta et al.[18]	Experimental	CT	USA (Southern California)	Forty male patients who were diagnosed with obstructive sleep apnea or were heavy snorers based on polysomnography with an age of 25-77 years. The patients' BMI ranged from 20.1 to 35.8 kg/m^2.	A significant negative correlation was found between BMI and airway volume, and a significant positive correlation was found between BMI and tongue volume. Airway volume was not significantly correlated with mandibular volume or tongue volume, but it was negatively correlated with the ratio of tongue volume to mandibular volume.
Uysal et al.[14]	Retrospective	CBCT	Turkey	CBCT images of 60 participants aged 16-36 years with class I malocclusion; normal growth and development; all teeth present, good facial symmetry; no significant medical history or trauma; and no previous orthodontic, prosthodontic, plastic, or maxillofacial surgery or treatment.	Patients with mild lower incisor irregularities displayed a greater tongue volume than those with severe irregularities. A significant inverse correlation between lower incisor irregularity and tongue volume was found in male patients, while no significant correlation between tongue volume and incisor irregularity was found among the female participants.
Iwasaki et al.[25]	Retrospective	CBCT	Japan	The rapid maxillary expansion (RME) group consisted of serial CBCT images of 28 participants (13 men, 15 women). The control group consisted of serial CBCT images of 20 participants (8 men, 12 women) without a history of RME device treatment.	Intraoral airway volume decreased significantly in the RME group after RME. A significant increase was found in total pharyngeal airway retropalatal and oropharyngeal airway volume. Total pharyngeal and oropharyngeal airway volumes increased significantly in the control group, but intraoral and retropalatal airway volumes did not change significantly.
Ahn et al.[19]	Retrospective	CT	Korea	Medical records of 64 Korean male patients with normal to severe obstructive sleep apnea who underwent overnight polysomnography, lateral cephalometry, and CT of the paranasal sinuses. Patients ranged in age from 20 to 71 years.	Tongue volume was significantly negatively correlated with the lowest level of O_2 saturation. High BMI was a relevant factor for an increase in absolute tongue volume, and the volume did not differ significantly between the normal-mild and moderate-severe groups, although the tongue volume to inner mandibular area in the moderate-severe group was significantly higher.
Hirata et al.[22]	Experimental	CT	Brazil	Men aged 18-65 years who were referred for investigation of obstructive sleep apnea and who underwent polysomnography and upper airway CT with negative expiratory pressure and critical closing pressure.	Patients with severe obstructive sleep apnea showed higher BMI, critical pharyngeal closing pressure, and negative expiratory pressure. Patients with higher upper airway collapsibility had a higher BMI and increased tongue dimension, as well as tongue volume, pharyngeal length, and soft palate length.
Schorr et al.[23]	Experimental	CT	Brazil	Japanese-Brazilian and white men matched for age (aged 18-70 years) and severity of obstructive sleep apnea by the apnea-hypopnea index (±7 events/hour).	White participants had a greater tongue length and volume and a greater tongue-to-mandibular volume ratio. A greater tongue volume-to-mandibular volume ratio was associated with passive critical closing pressure among white participants.
Abdallah et al.[26]	Prospective	CT	Canada	A total of 42 outpatients, aged 18-85 years and scheduled for high-resolution CT scanning of the head and neck as part of the management of lymphoma, breast, bladder, or cervical cancer.	Computed tomography measurements of the ratio of tongue thickness to oral cavity height were strongly correlated with the ratio of tongue volume to oropharyngeal cavity volume.
Ding et al.[16]	Experimental	CBCT	Japan	A total of 20 participants (10 men, 10 women) aged 26.5 to 34.7 years, with normal occlusion with 1-3 mm overjet and overbite and class I molar relationship.	A significant correlation was found between the volumes of the tongue and the oral cavity, but no significant correlation was noted between the volumes of the tongue and the oral cavity proper.
Mouhanna Fattal et al.[24]	Retrospective	CBCT	Lebanon	A total of 54 adult men: 27 suffering from obstructive sleep apnea and 27 with no history of sleep disorders.	Craniofacial structures did not differ significantly between groups. The mean upper airway volume in the obstructive sleep apnea group was smaller than that in the control group, while the post-hyoid volume, posterior volume, and their ratio to the total volume were greater in the apnea group than in the control group.

Table 1. Continued

Author	Study design	Imaging modality	Origin	Sample	Results
Iwasaki et al.[27]	Retrospective	CBCT	Japan	A total of 60 orthodontic treatment patients with an average age of 9.2 years were divided into 3 groups: class I, II, and III malocclusion. Class I included 9 boys and 11 girls, class II 9 boys and 11 girls, and class III 9 boys and 11 girls.	Tongue volume was positively correlated with oral cavity volume. Tongue volume was greater in class III participants than in class I and class II participants. The anatomical balance (tongue volume and oral cavity volume) was greater in class II than in class I participants.
Garber et al.[20]	Retrospective study	CT	USA	Nineteen participants (18 men and 1 woman) received chemoradiation therapy (CRT) as primary treatment for tonsillar or hypopharyngeal squamous cell carcinoma. Criteria included an age >18 years, squamous cell carcinoma with post-CRT as primary treatment, and CT imaging and follow-up CT imaging within 2 years of treatment.	A mean decrease of 0.45 cm^3 in tongue volume per month after chemoradiation therapy was reported. Body mass index was a strong predictor of tongue volume.
Halim et al.[29]	Retrospective study	CBCT	USA	Ten Caucasian participants aged from 24.7 to 36.3 years who underwent CBCT scanning. All participants had class I malocclusion and 1-3 mm overjet and overbite.	Three-dimensional CBCT evaluation of the tongue space, including tongue volume, oral cavity, and air capacity, can be a reliable and reproducible method.
Teramoto et al.[28]	Experimental study	CBCT	Japan	Fifteen participants (4 men, 11 women) aged from 19.74 to 32.65 years, scheduled to undergo orthognathic surgery for the correction of skeletal class III malocclusion.	A correlation was found between the decrease in oral cavity capacity and tongue volume after orthognathic surgical procedures. The volumetric ratio between the tongue and the oral cavity appears to be maintained.
Rana et al.[1]	Prospective study	CBCT	India	CBCT images of 15 participants (8 male, 7 female) aged 15-33 years (3 participants with skeletal class II malocclusions, 7 with skeletal class III malocclusions, and 5 with class I malocclusions).	A significant positive correlation was noted between the ratio of tongue volume to oral cavity volume and the tongue volume. The ratio of the tongue volume to the oral cavity proper volume was negatively correlated with the volume of the oropharynx. Tongue volume, oral cavity volume, and oral cavity airway volume showed a negative correlation.
Rajkumar et al.[21]	Retrospective study	CT	India	Twelve CT images of male patients before and after surgery; inclusion criteria were adequate data, age 18-25 years, lack of craniofacial abnormalities, normal BMI, single jaw surgery: bilateral sagittal split osteotomy without genioplasty, and follow-up CT records available from 3 months after surgery.	A strong positive correlation was found between oral cavity proper volumes before and after bilateral sagittal split osteotomy. Additionally, a positive correlation was observed between the tongue volumes before and after surgery.
Grover et al.[17]	Retrospective study	CBCT	India	A total of 60 pre-orthodontic CBCT records of participants aged 14-25 years. Patients were divided into 3 groups based on the FMA angle.	The average tongue volume was similar across groups, with variations in growth patterns. In those with vertical and horizontal growth patterns, maxillary length and palatal vault depth had a significant relationship with tongue volume and a highly significant correlation between the interpremolar and intermolar widths with tongue volume, while in those with the mean growth pattern it correlated significantly with tongue volume.

CT: computed tomography, CBCT: cone-beam computed tomography, BMI: body mass index, FMA: Frankfort-mandibular plane ang

volume ratio was negatively correlated with the oral cavity airway volume. Another study by Halim et al.[29] found that 3-dimensional CBCT evaluation of the tongue space, including tongue volume, oral cavity, and air capacity, was reliable and reproducible (as indicated by the ability to duplicate measurements across raters).

Tongue volume and CT

The use of CT in tongue volume measurement revealed a significant positive correlation with BMI. The index has been shown to be a strong predictor of tongue volume.[18-20] An increase in tongue volume was observed after bilateral sagittal split osteotomy.[21] A separate study by Garber et al.[20]

described a decrease in tongue volume after chemoradiation therapy. In studies of obstructive sleep apnea, no significant difference in tongue volume was seen between the control group and participants with mild, moderate, and severe obstructive sleep apnea.[18,19,22] In a study on airway volume, Shigeta et al.[18] found no significant correlation with mandibular volume or tongue volume. Another study on upper airway collapsibility by Hirata et al.[22] explained that greater upper airway collapsibility is associated with increased dimensions of the tongue (area and volume). A study on upper airway collapsibility by Schorr et al.[23] found that white participants had a greater tongue length and volume than Japanese-Brazilian participants. A greater imbalance in the tongue/mandibular volume ratio was also observed in white participants than in Japanese-Brazilian participants.

Tongue volume and oral cavity volume on CT

A strong positive correlation was found between the volumes of the oral cavity proper before and after bilateral sagittal split osteotomy. A positive correlation was also found between tongue volumes before and after surgery.[21] A study by Shigeta et al.[18] on the ratio of tongue volume to mandible volume relative to airway volume was identified and utilized CT images. Airway volume was found not to be significantly correlated with the ratio of tongue volume to mandibular volume. A separate CT measurement study by Abdall et al.[26] on the ratio of tongue thickness to oral cavity height showed a strong correlation with the ratio of tongue volume to oropharyngeal cavity volume.

Discussion

In the present study, all authors who discussed the reliability of CBCT agreed that this 3-dimensional method is a promising alternative for evaluating tongue and oral cavity volumes. Halim et al.[29] reported that 3-dimensional CBCT evaluation of the tongue space, including tongue volume, oral cavity, and air capacity, could be a reliable and reproducible method. This aligns with Ding et al.,[16] who stated that 3-dimensional volumetric measurement of CBCT images with contrast agents may be considered accurate and reliable and could assist in the identification of soft tissue boundaries. The majority of authors established a standardized protocol for CBCT imaging to reduce variability. This is very important because small changes in the position of the patient's head or tongue could affect the accuracy of the measurement. CBCT exhibits a very good intraclass correlation coefficient that includes both good intra-rater and inter-rater measurements; therefore, CBCT is considered accurate, reliable, and reproducible in evaluating the volumes of the tongue and oral cavity.

When evaluating the volumetric structure of the oral cavity, all aspects of the oral environment must be considered, including the position of the tongue. A low tongue position was associated with upper airway obstruction.[30] This condition was due to the obstruction that led to mouth breathing, which resulted in a lower tongue position and narrowing of the maxillary dental arch.[31] RME has been widely used to increase the transverse dimensions of the maxilla and was considered able to change tongue posture.[25,30] This is in accordance with Iwasaki et al.,[25] who reported a significant decrease in intraoral airway volume and a significant increase in total airway volume in patients after RME treatment. Intraoral airway volume refers to the volume between the tongue and palate and is the same as the oral cavity proper, which was evaluated as a vertical indication of tongue position. RME expanded the maxillary arch so that the total airway volume was increased and corrected the position of the tongue so that the intraoral airway volume was decreased.[25,31] The results were similar to those of Rajkumar et al.,[21] who found that the volume of the oral cavity proper was influenced by the position of the tongue, the space around the tongue, and the relationship between the maxilla and mandible. A study conducted by Ding et al.[16] found no significant correlation between the volumes of the tongue and the oral cavity proper. A similar statement was also made by Rajkumar et al.,[21] in their study showing no correlation between the post-surgery volumes of the oral cavity proper and the tongue. Therefore, the oral cavity proper volume is correlated with tongue position but is not correlated with tongue volume.

According to the equilibrium theory, the ratio of tongue volume to oral cavity capacity might contribute in maintaining a stable dental arch shape and correct occlusion.[32] The interaction of the tongue and facial muscles determined the structure of the dental arch, since the teeth are functionally stable within the alveolar bone.[17] Hence, malocclusion and constriction of the dental arches can be caused by an imbalance between the outward forces and inward forces from the cheeks and lips. This aligns with the findings of Uysal et al.,[14] who stated that tongue volume, tongue posture, and tongue function played an important role in the etiology of malocclusion and dentofacial deformity. Those authors evaluated the relationship between tongue volume and mandibular incisor irregularity from CBCT data and found greater tongue volume in patients with mild than in those with severe mandibular incisor irregularity.[14] A greater tongue volume was associated with a lower risk of lingual incisor collapse and thus resulted in lower irregularity values.[14] The previous study differed from that by Grover et al.,[17] who used CBCT to evaluate tongue volume in participants with 3 different growth patterns (mean, vertical, and horizontal growth) and found that mean tongue volume was statistically similar in all groups, indicating an indirect role of the tongue in malocclusion. That study also mentioned that interpremolar and intermolar width were an important factor in maintaining the size of the dental arch, as these measurements were correlated significantly with the volume of the tongue.[17] Overall, the tongue volume may have an important role in determining the tooth position and occlusion, along with the interaction with the facial musculature.

Importantly, according to Wickwire et al.,[33] the tongue (which can include tongue position, tongue function, or both) anatomically and physiologically responded to changes in the oral environment, and the tongue also adapted to the size of the surrounding mandibular arch. The study aligns with that of Teramoto et al.,[28] who found that the volumetric ratio between the tongue and the oral cavity appeared to be maintained after orthognathic surgery. The external tongue muscles attached directly to the mandible, causing the tongue to shift its position as the mandible moved, so that the decrease of oral capacity and tongue volume was interrelated.[28] Additionally, Rajkumar et al.[21] reported an increase in tongue volume after bilateral sagittal split osteotomy surgery or mandibular advancement surgery. However, that increase in tongue volume was caused by a surgical procedure to correct a skeletal class II malocclusion; the procedure corrected the position of the mandible, and the tongue in the mandibular arch adapted to the changes. Garber et al.[20] showed a decrease in tongue volume after chemoradiation therapy in patients receiving treatment for tonsillar or hypopharyngeal squamous cell carcinoma. Furthermore, the decrease in tongue volume and strength may disrupt the normal function of the organ, specifically leading to an inability to propel the bolus and thus affecting swallowing.

This systematic review identified several studies that discussed the tongue and oral cavity volumes in participants with obstructive sleep apnea. Upper airway collapse during sleep, also known as obstructive sleep apnea, is a disorder in which breathing stops intermittently and repeatedly for 10 seconds or more during sleep.[19,35] The cause depends on the part of the upper respiratory tract that is affected; when it is the posterior part of the tongue, the tongue muscles relax during sleep and the tongue falls backward, blocking the airway.[35] Mouhanna-Fattal et al.[24] found that the oral cavity volume in participants with obstructive sleep apnea did not differ significantly from that in the control group, but the upper respiratory tract volume was smaller in the apnea group, indicating upper respiratory tract obstruction. Another study conducted by Ahn et al.[19] stated that absolute tongue volume did not differ between a normal group with mild obstructive sleep apnea and a moderate-to-severe apnea group. In contrast, Hirata et al.[22] mentioned that patients with higher upper airway collapsibility experienced an increase in tongue dimensions, which included tongue area and volume. Hence, the results in this review included similar oral cavity and tongue volumes among patients with obstructive sleep apnea and the control group, as well as increased tongue dimensions among patients with higher upper airway collapsibility.

In the present review, several studies described the use of CBCT in examining the volumetric correlation between the tongue and the oral cavity. Previous studies by Ding et al.[16] and Iwasaki et al.[27] described a significant and positive correlation between tongue volume and oral cavity volume. This is in accordance with Rana et al.,[1] who also found a significant and positive correlation between tongue volume and the ratio of tongue volume to oral cavity volume. Similar results were described by Teramoto et al.,[28] who reported a correlation between the decrease in the oral cavity capacity and the tongue volume after orthognathic surgery. Regarding the surgical procedures, hyoid bone positioning and anteroposterior jaw positioning may have affected the airway dimensions, which should be considered during orthognathic surgery.[37] Overall, all authors who studied the correlation between the volumes agreed that the tongue volume and oral cavity volume were positively correlated. In this study, data on the absolute volumetric ratio of normal tongue and oral cavity sizes were not obtained, because no studies described either the normal tongue size/volume or a pathologically enlarged tongue. However, the percentage ratio of tongue volume to oral cavity volume in normal participants has varied across several studies. Ding et al.[16] reported a ratio of $91\% \pm 5\%$, while Iwasaki et al.[27] reported a ratio of 80.57%. Another percentage, 86.98%, was reported by Iida-Kondo et al.[34] A relatively large tongue in a normal-sized oral cavity or a normal-sized tongue in a small oral cavity can induce airway blockage by moving posteriorly.[1,35] This aligns with Rana et al.,[1] who reported that the volume of the tongue and oral cavity may relate to that of the upper airway. The study explained that the ratio of tongue volume to oral cavity volume was negatively correlated with the volume of the oropharynx, which means that if the tongue volume increases while the oral cavity volume remains constant, the oral cavity cannot accommodate the increase and the tongue moves posteriorly, causing the volume of the oropharyngeal canal to decrease. In addition, if the volume of the oral cavity decreases with a constant tongue volume, the oropharyngeal tract will also shrink, contributing to airway obstruction.[1] This study had similar findings to Shigeta et al.,[18] who reported that the volume of the airway was negatively correlated with the ratio of the volume of the tongue to the volume of the mandible. Notably, anatomically, the posterior third of the tongue is located in the oropharynx (a part of the upper airway), so changes in tongue volume would greatly impact the airway.

The tongue has a much higher fat percentage than other somatic muscles, and its fat content increases with increasing BMI.[16,36] A study by Ding et al.[16] found a significant correlation between tongue volume and BMI, reflecting the relationship between fat content and BMI. This study aligns with those of Shigeta et al.,[18] Ahn et al.,[19] and Garber et al.,[20] who stated that BMI was a strong predictor of tongue volume and was a relevant factor for an increase in tongue volume; in addition, a significant positive correlation was found between those factors. Hence, BMI plays an important role in determining the fat content of the tongue. A study conducted by Schorr et al.[23] found that white participants had a greater tongue length and volume and a greater soft tissue-to-bone structure imbalance (tongue/mandibular ratio) than Japanese-Brazilian participants. A later study by Iwasaki et al.[27] found that the tongue volume was greater in participants with class III than in those with class I malocclusions, while the anatomical balance (tongue volume to oral cavity volume) was greater in the class II than in the class I group. Abdallah et al.[26] reported a strong correlation between the ratio of tongue volume to oropharyngeal cavity volume and the ratio of tongue thickness to oral cavity height. Therefore, in the present review, we found variation in tongue volume among participants of different races and with different malocclusion types.

Based on the review of studies that met the criteria, CBCT has clearly been used in the volumetric evaluation of the tongue and oral cavity. Specifically, it has been utilized to examine the correlation between those volumes; to determine the relationship between tongue volume and various factors such as tooth position, occlusion, and BMI; to evaluate the relationship of tongue and oral cavity volumes with the upper airway; to evaluate the tongue and oral cavity volumes after surgical and non-surgical procedures; and to evaluate these volumes in patients with obstructive sleep apnea and malocclusion. Finally, the reliability of CBCT in measuring tongue volume and oral cavity capacity has also been assessed. In the included studies, CT was used for similar purposes as CBCT, although its reliability was not evaluated. A limitation of this systematic review was that some relevant studies may not have been covered because they were excluded by the search criteria and the year of publication. The authors suggest further research based on this systematic review and with a higher level of evidence, and that future investigations should specifically address the main gap in the present study: the lack of data on the absolute volumetric ratio of normal tongue and oral cavity sizes, which have not been yet identified in any studies. This is a potential area of interest for further studies, with our study serving as preliminary research.

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Conflicts of Interest: None

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