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REVIEW

Radiographic and diagnostic approaches for mandibular asymmetries in orthodontic practice: a narrative review

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Abstract

Mandibular asymmetry refers to dimensional differences between the left and right sides of the mandible in terms of size, form and volume. This condition may result in problems with functionality as well as appearance. Early intervention is often deemed optimal for addressing mandibular asymmetry; however, there is a lack of consensus regarding the diagnostic approach and strategy for identifying asymmetries in developing individuals. The purpose of this narrative review (NR) is to provide a clinician-focused update on the radiographic techniques for identifying mandibular asymmetries in orthodontic patients. Selective database searches were conducted until November 2023 to assess the available literature on mandibular asymmetry diagnosis. A health-sciences librarian developed a search strategy utilizing appropriate terms associated with mandibular asymmetry diagnosis. The databases used were Web of Science, Embase, Scopus, Liliacs and PubMed. Fifty-two studies were included in this review and data regarding the evaluation of mandibular asymmetries were presented with a narrative approach delineating clinical indications based on retrieved findings. There is no unanimous consensus on the method for diagnosing mandibular asymmetries. Cone beam computed tomography emerges as the preferred examination method for diagnosing mandibular asymmetry, thanks to the assessment of a 3D structure with a 3D image. However, the use of only orthopantomography could be advisable as a first-line diagnostic tool in children due to less radiation exposure.

Keywords

Mandibular asymmetry; Orthodontics; Radiographic diagnosis

1. Introduction

Facial asymmetry occurs in 34–38.6% of patients with dentofacial deformities [1] as opposed to 23% in the orthodontic population [2]. Every subject exhibits a dominant half-face, predominantly the right side in 80% of cases, with equal distribution across sexes and age groups [3]. Additionally, with 40–80% of cases affecting the lower third of the face, this area is the most commonly affected by facial asymmetry [1, 4]. The increased frequency of lower facial asymmetry has been attributed to the mandible's mobility and longer growth period than that of the maxilla [5].

Mandibular asymmetry can arise from a misalignment between the midface and the mandible (positional asymmetry) or differences in size and shape between the two halves of the mandible (shape asymmetry) [6]. Multifactorial mandibular asymmetry is linked to cleft lip and palate, posterior crossbite, temporomandibular disorder (TMD), and various skeletal patterns [7–12]. In particular, congenital asymmetry can be caused by hypoplasia or hyperplasia of the ramus and condyle [13], while acquired asymmetry is linked to tumors, infections, rheumatoid arthritis, osteoarthritis of the temporomandibular joint, and myogenic issues like myospasm, persistent muscle shortening, splinting, or occlusal interferences [13–15].

Mandibular asymmetry may potentially benefit from early detection and treatment, according to some research findings [16]. It is imperative for orthodontists to evaluate this condition since one of the primary treatment objectives is to achieve facial symmetry and balance, reflecting the overall harmony of the face and jaw [14]. A preliminary evaluation would include a detailed facial and soft-tissue analysis with specific focus on the chin's center, the lip commissures' leveling, and the bilateral symmetry of the mandibular body contours and gonial angles. Additionally, smile and occlusal examinations should determine whether the dental midlines align with the facial midlines, the occlusal plane's inclination, and the degree of gingival exposure on both sides [17].

The secondary level diagnosis of mandibular asymmetry involves the radiographic assessment of hard tissues. Before the advent of 3D (three dimensional) imaging radiology, 2D (two dimensional) imaging were used to assess skeleton-facial asymmetry, including posteroanterior (PA) cephalograms, submentovertex and orthopantomography (OPT). However, 2D radiographic imaging present inherent limitations that can lead to underestimate the presence of skeletal asymmetry [18]. The advent of Computed tomography (CT) and Cone beam Computed tomography (CBCT) has added the third dimension to the skeletal evaluation thereby overcoming the limitations associated with 2D radiography [19]. In addition, it has been proposed the usage of other methods of diagnosis, such as Magnetic resonance imaging (MRI), scintigraphy, single photon emission computed tomography (SPECT), photos or laterolateral teleradiography (TELE LL). Such radiographic tools, both 2D and 3D, have been tested and validated for the analysis of facial asymmetry under specific conditions [18, 20, 21].

However, as far as the actual evidence is concerned, there are not studies in literature that provide a comprehensive overview of the radiological technologies involved in the analysis of mandibular asymmetry, neither a definitive protocol for selecting the appropriate radiographic tool for diagnosis of mandibular asymmetries in growing subjects. Consolidating this information would aid pediatric dentists and orthodontists in selecting the appropriate radiographic tool, as suggested by the authors of this review.

In this regard, the present systematic-narrative hybrid review (HR) aims to offer a clinician-focused update on the methods for radiological diagnosis of mandibular asymmetries in orthodontic patients during growth. This review intends to comprehensively analyze various methods across different domains to provide a thorough understanding of the available diagnostic approaches.

2. Materials and methods

The current manuscript's structure complies with the essential elements of the recommended SR methodology [22].

2.1 Research question

To delineate the scope of the search strategy, we formulated a central research question that orthodontists could reference for guidance: "What are the appropriate radiological methods for diagnosing mandibular asymmetries according to evidence-based medicine?".

2.2 Justification

The rationale for conducting the current NR (narrative review) stemmed from the lack of a thorough and comprehensive overview in the literature concerning the diagnostic method of mandibular asymmetries in orthodontic patients during growth. The search procedures and inclusion/exclusion criteria for this purpose are based on the consolidated methodology for Systematic Reviews (SRs) [23], and the selected articles underwent analysis using a narrative approach [22].

2.3 Eligibility criteria

With the exception of reviews, all research on mandibular asymmetries diagnostic techniques in orthodontics was taken into account. The language was unrestricted and the publication year was limited from 2013 to 2023, to consider only the most up-to-date diagnostic methods. Studies were included if they met the following criteria outlined according to the PICO format: studies conducted in growing human subjects (Participants); studies analyzing mandibular asymmetry using radiographic examination (Intervention), studies evaluating different type of radiographic tools used for the diagnosis of mandibular asymmetry (Comparison), mandibular asymmetry calculated *via* 2D or 3D dataset (Outcomes).

2.4 Literature sources and search parameters

To assess the corpus of current literature on the subject, multiple database searches were carried out through November 2023. The development of a search strategy that incorporated all discovered keywords and free-standing terms was aided by a health sciences librarian. The Web of Science, Embase, Scopus, Liliacs and PubMed databases were utilized. Additionally, further research was conducted to validate each source of evidence listed in the reference list. The results of customizing the search approach for each database are presented in Table 1.

2.5 Data cleaning

2.5.1 Study selection

Following the retrieval of search results from each electronic database, the citations were imported into EndNote X9, a reference manager program developed by Clarivate^{TM}, London, UK. Reports that were duplicates were eliminated, and articles that provided updates or preliminary findings were only assessed once. Two authors, V.R. and S.L.R., independently screened all titles and abstracts retrieved from the databases before proceeding to read the full texts of relevant studies. Any discrepancies in the assessment of study eligibility were resolved through consultation with an additional author, L.R. The degree of agreement between the two reviewers has been assessed using Cohen's kappa statistics.

2.5.2 Data extraction

In order to gather the characteristics and outcomes (study design, sample size and objectives) needed for the subsequent literature analysis, two authors (S.L.R. and V.R.) created a data extraction form. We had discussed any discrepancies with L.R., another author reviewer. Cohen kappa statistics has been employed to evaluate the degree of concurrence between the two authors.

2.6 Information synthesis

The findings from the selected papers had to be presented narratively to comply with the suggested method for HRs [22]. A methodology derived from previous studies published by other researchers was used to report the results [24]. To better address clinical indications, the results were organized and discussed into distinct domains that included all the data retrieved from the included studies.

TABLE 1. Terms used on database search.

Database	Search format
PubMed	((“cbct”(All Fields) OR (“imaging, three dimensional”(MeSH Terms) OR (“imaging”(All Fields) AND “three dimensional”(All Fields)) OR “three-dimensional imaging”(All Fields) OR (“3d”(All Fields) AND “imaging”(All Fields)) OR “3d imaging”(All Fields)) OR (“radiography, panoramic”(MeSH Terms) OR (“radiography”(All Fields) AND “panoramic”(All Fields)) OR “panoramic radiography”(All Fields) OR “orthopantomographies”(All Fields) OR “orthopantomography”(All Fields)) OR (“edrecolomab”(Supplementary Concept) OR “edrecolomab”(All Fields) OR “panorex”(All Fields)) OR (“radiography, panoramic”(MeSH Terms) OR (“radiography”(All Fields) AND “panoramic”(All Fields)) OR “panoramic radiography”(All Fields) OR (“panoramic”(All Fields) AND “radiography”(All Fields))) OR (“antero-posterior”(All Fields) AND (“cephalogram”(All Fields) OR “cephalograms”(All Fields))) OR ((“axial”(All Fields) OR “axially”(All Fields) OR “axials”(All Fields)) AND (“cephalometries”(All Fields) OR “cephalometry”(MeSH Terms) OR “cephalometry”(All Fields))) OR (“2d”(All Fields) AND (“image”(All Fields) OR “image s”(All Fields) OR “imaged”(All Fields) OR “imager”(All Fields) OR “imager s”(All Fields) OR “imagers”(All Fields) OR “images”(All Fields) OR “imaging”(All Fields) OR “imaging s”(All Fields) OR “imagings”(All Fields))) OR (“diagnosable”(All Fields) OR “diagnosi”(All Fields) OR “diagnosis”(MeSH Terms) OR “diagnosis”(All Fields) OR “diagnose”(All Fields) OR “diagnosed”(All Fields) OR “diagnoses”(All Fields) OR “diagnosing”(All Fields) OR “diagnosis”(MeSH Subheading))) AND ((“mandible”(MeSH Terms) OR “mandible”(All Fields) OR “mandibular”(All Fields) OR “mandibulars”(All Fields)) AND (“asymmetries”(All Fields) OR “asymmetry”(All Fields)) AND (“orthodontal”(All Fields) OR “orthodontic”(All Fields) OR “orthodontical”(All Fields) OR “orthodontically”(All Fields) OR “orthodontics”(MeSH Terms) OR “orthodontics”(All Fields)) AND (“young”(All Fields) OR “youngs”(All Fields)))) AND (y_10(Filter))
Embase *via* Ovid	((cbct or 3d imaging or orthopantomography or panorex or panoramic radiography or antero-posterior cephalogram or axial cephalometry or 2d imaging or diagnosis) and (mandibular asymmetry and orthodontics and young)).
Web of science	(ALL = (((cbct) OR (3d imaging) OR (orthopantomography) OR (panorex) OR (panoramic radiography) OR (antero-posterior cephalogram) OR (axial cephalometry) OR (2d imaging) OR (diagnosis)))) AND ALL = (((mandibular asymmetry) AND (orthodontics) AND (young)))
Scopus	((cbct) OR (3d AND imaging) OR (orthopantomography) OR (panorex) OR (panoramic AND radiography) OR (antero-posterior AND cephalogram) OR (axial AND cephalometry) OR (2d AND imaging) OR (diagnosis)) AND ((mandibular AND asymmetry) AND (orthodontics) AND (young)) AND PUBYEAR > 2012 AND PUBYEAR < 2024
Liliacs	(((cbct) OR (3d imaging) OR (orthopantomography) OR (panorex) OR (panoramic radiography) OR (antero-posterior cephalogram) OR (axial cephalometry) OR (2d imaging) OR (diagnosis)) AND ((mandibular asymmetry) AND (orthodontics) AND (young))

3. Results

After deleting duplicate files, the reviewers focused on 1429 out of the 1553 citations generated by the search strategy. Following the reading of the abstracts and titles, 1274 papers in total were eliminated, leaving 155 articles for full-text assessment. Following a comprehensive analysis of these articles, 52 studies were deemed suitable for evaluation. The remaining 103 articles were excluded for various reasons: 6 of them were systematic reviews, 1 was case control, 8 were reviews, 2 were books and 86 had a topic not compatible with the study. Table 2 presents the characteristics of the included studies, while Fig. 1 provides an overview of the research selection process.

Moreover, the chosen articles required to clarify the efficacy model of Fryback and Thornbury: therapeutic efficacy, diagnostic thinking efficacy, diagnostic accuracy efficacy, or any combination of the aforementioned [25]. They proposed a hierarchical model in which demonstrating efficacy at each lower level is necessary but not sufficient to guarantee efficacy at higher levels. Level 1 addresses the technical quality of the images, whereas Level 2 deals with the diagnostic accuracy, sensitivity and specificity related to the image interpretation. Level 3 examines whether the information alters the diagnostic reasoning of the referring physician. Such a shift is a necessary precondition for Level 4 efficacy, which deals with the impact on the patient treatment plan. Level 5 efficacy studies assess the impact of information on patient outcomes. Level 6 evaluations, in the end, consider the advantages and disadvantages of a diagnostic imaging technology for society.

TABLE 2. Characteristics of the included primary studies articles included in the narrative review.

Author/year	Sample	Method	Type of study	Objective
Agrawal, 2015	10 patients	OPT	Retrospective study	The purpose of this study was to evaluate the accuracy with which orthopantomograms identify face asymmetries.
Ajmera, 2022	21 patients	CBCT	Prospective study	The purpose of the current investigation was to identify the location and degree of maxillomandibular asymmetry in asymmetric patients both before and after orthognathic surgery.
Ajmera, 2023	21 patients	CBCT	Prospective study	In order to determine the most effective approach for assessing craniofacial asymmetry, four distinct methodologies were used to analyze the results of corrective surgical treatment for the condition.
Alhazmi, 2023	131 patients	CBCT	Retrospective study	Mandibular condylar height, ramus height, total height, asymmetry index, and condylar volume in people with varying anteroposterior and vertical skeletal discrepancies are the parameters that will be measured in this study.
Alkis, 2023	100 patients	OPT and PA tele	Retrospective study	Comparing the asymmetry index found on digital panoramic radiography and posteroanterior cephalometric pictures was the aim of this investigation.
Bal, 2018	776 patients	OPT	Retrospective study	This study sought to determine the prevalence of age- and gender-related ramus asymmetries in a young population, as well as the impact of growth spurts on ramus asymmetry.
Bolat, 2021	104 patients	OPT	Retrospective study	Examining condylar, ramal and condylar + ramal mandibular vertical asymmetry in a group of patients with various vertical skeletal patterns was the goal of the current study.
Cavagnetto, 2021	133 patients	CBCT	Retrospective study	This study compares the volumetric variations of various mandibular segments in people with unilateral and bilateral juvenile idiopatic arthritis to control volumes that are not associated with the disease.
Chan, 2017	200 patients	SPECT	Retrospective study	The purpose of this study was to determine the sensitivity and specificity of SPECT bone scintigraphy in individuals with facial asymmetry resulting from condylar hyperplasia. Additionally, the study aimed to establish general trends in condylar growth across age and sex groups in the study population.
Espinosa, 2023	40 patients	SPECT	Retrospective study	The purpose of this research was to evaluate the SPECT diagnostic accuracy for unilateral condylar hyperplasia.
Fan, 2022	120 patients	CBCT	Retrospective study	The goal of this work was to create an automated workflow for the analysis of 3-dimensional mandibular shape asymmetry.
Faryal, 2022	118 patients	OPT and LL tele	Prospective study	The purpose of this study was to evaluate whether the linear mandibular measures obtained from the orthopantomogram's left and right sides were reliable. Additionally, the study aimed to determine whether the linear mandibular measurements obtained from these sides were identical to those obtained from the lateral cephalogram.

TABLE 2. Continued.

Author/year	Sample	Method	Type of study	Objective
García-Sanz, 2017	6 cadavers	CBCT	Observational study	The purpose of this study was to assess the accuracy and dependability of volumetric and linear measurements of the mandibular condyles using CBCT in the presence of soft tissues.
Goto, 2014	40 patients	MRI	Prospective study	The goal of this study was to look at the variations in mandibular morphology in patients with noncongenital skeletal mandibular asymmetry between the deviated and nondeviated sides.
Ha, 2022	120 patients	CBCT	Retrospective study	The purpose of this study was to categorize adult patients with skeletal Class III malocclusion's facial asymmetry characteristics.
Hasebe, 2019	166 patients	CBCT	Retrospective study	Utilizing CBCT, the purpose of this study was to evaluate condylar size between various anteroposterior and vertical skeletal patterns.
Hlatcu, 2023	214 patients	OPT	Prospective study	The purpose of this study is to evaluate posterior vertical mandibular asymmetries by computing the mandibular asymmetry index on panoramic radiography in various malocclusion types, taking into account sexual dimorphism in pediatric and adolescent patients, and comparing these groups.
Huang, 2017	32 patients	CBCT	Retrospective study	This study sought to evaluate the relationship between the condyle-glenoid fossa and first molar, as well as the features of dental and skeletal asymmetry in Class II subdivision malocclusion.
Huang, 2023	125 patients	CBCT	Prospective study	This study aimed to evaluate mandibular asymmetry in unilateral posterior crossbite patients and compare the asymmetry between adolescents and adults with unilateral posterior crossbite.
Kim, 2016	56 patients	CBCT	Retrospective study	The purpose of this study was to assess the volume and location of the condylar head and the glenoid fossa, two key temporomandibular joint structures, in patients who have facial asymmetry.
Kim, 2019	60 patients	CBCT	Retrospective study	This study used cone-beam computed tomography to assess dental compensation in face asymmetry and its relationship to skeletal factors.
Lemos, 2014	10 patients	OPT	Prospective study	The purpose of this pilot study was to suggest a new method for differentiating between morphological and functional mandibular asymmetry in children with and without unilateral posterior crossbite using digital panoramic radiography.
Leonardi, 2019	48 patients	CBCT	Retrospective study	The objective of this study was to compare the shape and morphology of the mandibular functional unit between the cross-bite and non-cross-bite sides in adult patients with posterior unilateral cross-bite who had not undergone any corrective treatment for malocclusion using three-dimensional mirroring and surface-to-surface techniques.
Leonardi, 2020	57 patients	CBCT	Retrospective study	The purpose of this study was to examine the hemi mandibular volumes from the crossbite and non-crossbite sides of the same patients, as well as the mandibular morphology in adults with posterior unilateral crossbite.

TABLE 2. Continued.

Author/year	Sample	Method	Type of study	Objective
Leonardi, 2021	40 patients	CBCT	Retrospective study	This study aimed to assess mandibular asymmetry in children with posterior unilateral crossbite using reverse engineering and cone-beam computed tomography both pre- and post-rapid maxillary expansion treatment.
Li, 2023	95 patients	CBCT	Retrospective study	This study used CBCT and three-dimensional reconstructive imaging to examine the condylar morphological changes and condyle-fossa relationship in patients with unilateral posterior scissors-bite.
Lim, 2018	43 patients	OPT and CBCT	Retrospective study	The aim of this study was to assess the diagnostic use of the asymmetry index on panoramic radiography and to compare its use with cone-beam computed tomography in the detection of mandibular posterior asymmetry.
Lima, 2018	40 patients	PET/CT	Prospective study	A low dosage 18F-Fluoride PET/CT procedure was developed because unilateral condylar hyperplasia patients are young, and it was compared to a typical injected activity scan to see if the image quality remained the same.
Liu, 2019	56 patients	SPECT/CT	Retrospective study	This study sought to determine whether precise region-of-interest drawings generated using CT images as a reference may yield quantification methods of SPECT plus CT that were more accurate than traditional SPECT methods for unilateral condylar hyperplasia growth evaluation.
Lopezb, 2016	61 patients	SPECT	Prospective study	This study compared two nuclear medicine tests—planar bone scintigraphy and single photon emission computed tomography—that are used to diagnose active condylar hyperplasia in terms of their dependability and connections with age and gender
Macrì, 2022	1 patient	CBCT	Case Report	CBCT was used in this case report to assess the progression and compensatory mechanisms of mandibular asymmetry in a developing male patient.
Malik, 2020	61 patients	PA tele	Retrospective study	This study aimed to assess potential variations in facial asymmetry between asymptomatic controls and patients with bilateral and unilateral degenerative joint disease.
Marques, 2023	96 patients	CBCT	Retrospective study	Using sagittal skeleton patterns as a guide, this study compared the mandibular morphology and transverse dental compensation of symmetrical and asymmetrical patients. Furthermore, the hypothesis that there were differences in mandibular morphology and dental compensations between asymmetrical and symmetrical groups as well as between the various sagittal skeletal pattern types was examined.
Miresmaeili, 2021	30 patients	CBCT	Retrospective study	This study evaluated the mandibular skeletal asymmetry in patients with unilateral posterior dental crossbite who were pre-orthodontic.
Nolte, 2015	132 patients	OPT	Retrospective study	The current study's objective was to statistically analyze the 2-dimensional panoramic radiographs that were available for a sizable group of condylar hyperplasia patients. These images are anticipated to be insufficient for standard diagnostic techniques and the condition's ongoing monitoring.

TABLE 2. Continued.

Author/year	Sample	Method	Type of study	Objective
Nolte, 2016	74 patients	CBCT	Retrospective study	This study's primary goal was to measure mandibular asymmetry in unilateral condylar hyperplasia patients using a dependable and repeatable technique. Secondly, the veracity of the current classification was assessed.
Nur, 2016	88 patients	CBCT	Retrospective study	CBCT was used in this work to: (1) assess face asymmetry in three dimensions; and (2) compare the volumetric properties of the right and left facial hard and soft tissues as well as their interactions with one another.
Oh, 2020	30 patients	CBCT	Retrospective study	The purpose of this research is to determine whether the menton deviation in face asymmetry is connected with the three-dimensional morphology of the mandibular condyle, glenoid fossa, and mandible.
Paknahad, 2018	60 patients	CBCT	Retrospective study	The current study compared people with normal occlusion to patients with unilateral and bilateral cleft lip and palate in terms of mandibular vertical asymmetry.
Park, 2013	67 patients	CT	Retrospective study	The purpose of this study was to create three-dimensional vectors for the mandibular functional units in order to assess mandibular asymmetry through the use of a vector-based method.
Pradnahan, 2023	126 patients	PA tele	Retrospective study	The study's objective was to measure and contrast the levels of craniofacial asymmetry in individuals with and without temporomandibular joint symptoms.
Rakauskatie, 2020	160 patients	LL tele	Prospective study	The purpose of this study was to examine the mandibular asymmetry in the sagittal direction of monozygotic and dizygotic twins using cephalometric data, as well as the effects of genetic and environmental factors on this asymmetry.
Ryu, 2015	85 patients	CBCT	Retrospective study	This study used CBCT to evaluate the rotational patterns of dentofacial structures in relation to various vertical skeletal patterns and examined their impact on menton deviation in skeletal Class III deformity with mandibular asymmetry.
Shetty, 2022	150 patients	CBCT	Retrospective study	Analyzing volumetric asymmetries between the left and right condyles in connection to dental status, age, and gender was the goal of this study.
Silvestrini-Biavati, 2014	28 patients	OPT	Prospective study	The purpose of this study was to finish Habets' orthopantomogram approach, which measures mandibular symmetry in mixed dentition both horizontally and diagonally as a preliminary diagnostic assessment.
Takahashi-Ichikawa, 2013	20 patients	OPT and CT	Retrospective study	to assess the accuracy of panoramic radiography and three-dimensional computed tomography in evaluating mandibular hypoplasia in patients with hemifacial microsomia.
Tam, 2023	50 patients	CBCT	Prospective study	In order to understand how soft tissue thickness affects overall asymmetry and whether menton deviation is associated with bilateral differences in soft tissue thickness and hard and soft tissue prominence, this study examined the hard and soft tissue asymmetry in skeletal Class III patients.

TABLE 2. Continued.

Author/year	Sample	Method	Type of study	Objective
Teng, 2021	40 patients	CBCT	Retrospective study	The purpose of this study was to examine mandibular symmetry, the occlusal plane, and their relationships using CBCT images in individuals with high-angle skeletal class III malocclusion and jaw deformity.
Thiesen, 2018	120 patients	CBCT	Retrospective study	The purpose of this study was to use CBCT to evaluate the features that affect skeletal Class I individuals with mandibular asymmetry.
Tun, 2021	50 patients	CT	Retrospective study	The purpose of this study was to assess the glenoid fossa's three-dimensional location and its connection to asymmetrical condylar translational movement in order to look into the morphological and functional implications on mandibular asymmetry.
Tun, 2022	50 patients	CT	Retrospective study	The purpose of this study was to assess the three-dimensional morphology of the temporomandibular joint and its correlation with asymmetric condylar mobility in individuals with mandibular asymmetry.
You, 2018	50 patients	CBCT	Retrospective study	This study used CBCT to examine the morphologic characteristics of skeletal units in the mandibles of patients with mandibular retrognathism and facial asymmetry.

OPT = Orthopantomography; CBCT = Cone-Beam Computed Tomograhpy; PA = Postero-Anterior Cephalogram; SPECT = Single Photon Emission Computed Tomography; LL = Latero-Lateral Cephalogram; MRI = Magnetic Resonance; PET/CT = Positron Emission Tomography/Computed Tomography.

The data are presented in a narrative review format, establishing domains to aid comprehension for clinicians (OPT, PA cephalogram, CBCT, other methods).

Eleven studies [26–36] focused on the usage of OPT to detect mandibular asymmetries, either alone or in conjunction with other diagnostic methods, such as teleradiography or CBCT. According to various studies [26, 30], through linear and angular measurements made in the radiography, it is possible to assess mandibular asymmetry, in particular on the vertical plane. An asymmetry index (AI) was proposed in 1988 by Habets [20] to assess the dimensions asymmetries of the mandibular ramus and condyle in panoramic radiographs (PR). Given that the asymmetry index may be computed using routine PR obtained, several studies based on this guide the diagnosis or a first screening tool in children [27–29, 31, 33–36].

In one study [32] the screening for mandibular asymmetry was made through an image processing software, ImageJ, to automate and facilitate measurements, avoiding clinician error.

Four studies [26, 27, 37, 38] evaluated the usage of PA cephalograms to achieve a mandibular asymmetry diagnosis. Through linear and angular measurements, one study [26] reported the importance of this radiographic technique as a primary diagnostic tool. This statement is corroborated by other articles [27, 38], which used the asymmetry index to identify mandibular discrepancies. The identification of valid landmarks is one of the principal problems of 2D imaging. To address this issue, one study [37] associated the PA cephalograms with lateral cephalograms and orthopantomography, both of them routine exams for an orthodontic patient.

The LL cephalometric exam was proposed in one study [39] to obtain mandibular asymmetry diagnosis. Another study [40], instead, used MRI 3D images, which proved to be effective in evaluating both the deviated and nondeviated side especially in early disease stages because it allows an excellent evaluation of the disc, especially in early disease. MRI employs non-ionizing radiation; and does not entail significant biological side effects. Four studies [41–44] assessed the use of SPECT. While three of these studies [41–43] concluded that SPECT was not beneficial, one study [44] found it to be more effective than scintigraphy for the diagnosis of condylar hyperplasia. Moreover, five studies [36, 45–48] proposed the usage of CT scans, in particular, one of them [45] focused on PET/CT instead of the SPECT for diagnosing active growth of the condyle. Mandibular asymmetries have been evaluated by a 3D vector system [46], with successful results. According to three studies [36, 47, 48], CT is an appropriate diagnostic tool for mandibular asymmetries, because it provides 3D imaging of 3D structures, but the high biological cost should be evaluated.

The usage of CBCT was assessed in thirty-one studies [5, 6, 18, 21, 33, 49–73], aiming to obtain a 3D image with a lower biological cost than spiral CT [49]. These articles proposed various ways to evaluate mandibular asymmetry, ranging from adaptating asymmetry index or linear measurements, to volume analysis, superimposition of models and reverse engineer mirroring. In a recent study [51], the authors employed four methods, on the same CBCT, to evaluate asymmetry:

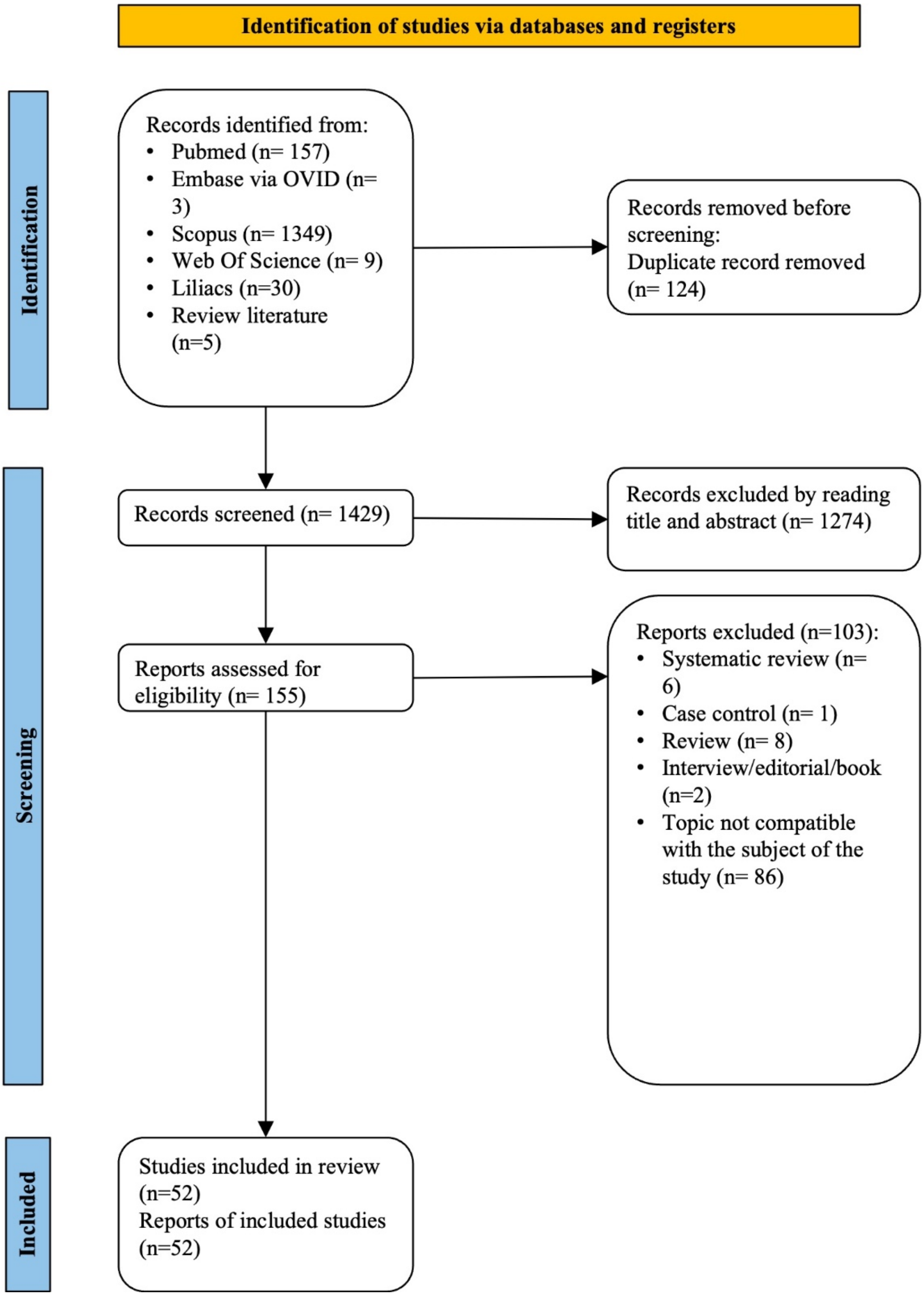

FIGURE 1. Flow chart for literature search.

asymmetry index, clinically derived midline, Procrustes analysis (PA), and modified Procrustes analysis (MPA). Unlike Procrustes analysis (PA), which used all face landmarks for aligning the original and reflected 3D configurations, MPA was created so that the superimposition was based only on 4 stable landmarks (bilateral orbitale and porion). The authors discovered that, similar to AI, the clinically derived midline (CM) and modified Procrustes analysis (MPA) were able to fully identify asymmetry, particularly in the mandibular region. In contrast, Procrustes analysis produced different outcomes in cases where the chin and mandible midline were symmetric. Another technique involves the usage of mirrored 3D overlaid models [74], which is based on the creation of a virtual 3D mandible and a mirrored counterpart, landmark identification and then measuring linear distances and models. The reverse engineering software method of superimposition and mirroring has been proposed by various authors [18, 61, 62] enabling the assessment of morphological symmetry of any anatomical structure or treatment effectiveness. To assess Euclidean distances between the surfaces of superimposed anatomical structures, 3D bone structures from CBCT scans are mirrored and then superimposed. Using a method known as “surface-to-surface” analysis, the software also enables the evaluation of the morphological differences between superimposed structures in various colors on a 3D color map by varying the tolerance levels. Two studies [5, 21] focused not only on hard tissue asymmetry but also on soft tissue one, reporting that the combination of these conditions should be considered for developing an accurate treatment plan.

4. Discussion

Pediatric dentists and orthodontists are called to possess a comprehensive expertise in diagnosing of facial asymmetry in growing subjects. In this regard, clinicians should be able to identify all the features involved in the process of asymmetry, analyzing disharmony both qualitatively and quantitatively. Skeletal asymmetry might involve a single structure, however, it could affect the structures of antagonist basal bone as growth compensation process [24]. Concerning facial structures, the mandible is the jaw mostly affected by asymmetries, with maxillary asymmetric growth occurring as compensatory mechanism to maintain function and occlusion [60]. Mandibular asymmetries might involve the condyle, ramus, mandibular body and symphysis, all of which might experience changes in size, volume or position. In all these circumstances, radiographic examination represents a fundamental step in the diagnostic process of skeletal asymmetry since it allows to discriminate and to distinguish the structures and relative area/regions affected.

To the best of our knowledge, this is the first contribute in the literature that provides an updated detailed description of the radiographic tools usable for implementing the diagnosis of mandibular asymmetry, providing the rationale for clinical usability according to the evidence retrieved from included studies. In this regard, various methods have been explored, each with its own merits and limitations.

4.1 OPT

Since OPT is the standard preliminary radiographic record for orthodontic purpose, it may be utilized as a screening radiographic tool to identify the need for more in-depth radiographic studies and to detect early vertical mandibular asymmetries [30]. Indeed, OPT can assess condyle or ramus height vertically with acceptable consistency and reliability [75, 76] making it suitable for preliminary detection of condylar or ramal asymmetry. However, OPT has limitations, including limited resolution and susceptibility to picture distortion, magnification, and the superposition of anatomic structures [75, 77]. Considering that posterior structures (*i.e.*, condyle and ramus) are subjected to less vertical distortion compared to anterior regions, high-quality OPT can be considered a non-invasive, acceptable diagnostic tool for screening vertical asymmetry of the mandible [20, 78]. However, a standardized protocol, which involves two aspects, is warmly encouraged to avoid reduction of diagnostic accuracy. Firstly, it is important that the distance between the film and the X-ray tube’s focus point is the same in order to avoid vertical amplification [79]. Secondly, head posture during x-ray acquisition must be standardized since there is evidence [78] that a 10 mm shift in head position could result in a 6% vertical size difference. Such posture discrepancy can influence the analysis of asymmetry, especially considering that, according to Habets [20], mandibular posterior vertical asymmetry is defined as asymmetry index values higher than 3%.

The utilization of Habets’ Asymmetry Index [20], which focuses on linear and angular measurements, can enhance the precision of assessing mandibular conditions, providing orthodontists with a quantitative tool to evaluate the severity and direction of asymmetries. This index can be evaluated by direct tracing with a pencil, or with a computer software [32]. The benefit of the study presented is that it enables simultaneous evaluation of mandibular measures in individuals, facilitating the differential diagnosis of morphological and functional mandibular asymmetries.

4.2 PA cephalogram

The PA cephalogram has long been utilized in orthognathic and orthodontic diagnosis, as well as in surgical planning, to examine the transverse dimension of the craniofacial skeleton and dentoalveolar structures, hence to address asymmetry [24, 80]. In one study [27] PA cephalometric analysis in orthodontics has been compared with orthopantomography as a diagnostic tool for mandibular asymmetries, using the asymmetry index. When the measurement values were entered into the AI formula, the results did not indicate a significant difference between the PR and PA cephalogram images, suggesting that both methods can be used for diagnosis. However, measurements such as the condylar height (CH), ramus height (RH), and CH + RH showed statistically significant differences on the right and left sides in panoramic radiographs (PR) and posteroanterior cephalometric radiographs (PACR) [27]. Another study [26] compared PA cephalometry with OPT using linear and angular measurements, concluding that there is a strong diagnostic correlation between the two methods. Therefore, the combination of both techniques allows for initial diagnostic screening. Nevertheless, as for panoramic radiograph, also posteroanterior teleradiography is a 2D image of 3D structures, and the head position has a significant impact on the vertical dimension, making it unsuitable for distance measurements [80].

4.3 Latero-lateral cephalogram

In this section of the discussions, studies referring to diagnostic methods of mandibular asymmetry not commonly employed are evaluated. A lateral cephalogram can contribute to the diagnosis, follow-up, and management of various dentofacial deformities and growth anomalies by evaluating interactions among the skull, face, and teeth [81]. However, due to the overlap of the two sides’ structures and superimposed pictures, the lateral cephalogram is unable to compare the orofacial features on the right and left [30].

4.4 Computed tomography methodologies

The 3D anatomical reconstruction ensures excellent visualization of both hard and soft tissues and, consequently, allows for a better definition of the discrepancy of the same structure between both sides. In assessing facial asymmetry, CT scans offer high-resolution images that allow for precise visualization of different areas of the mandible facilitating the identification of asymmetrical growth patterns, structural abnormalities, and deviations from normal anatomical configurations. By employing cross-sectional imaging, CT facilitates the examination of specific regions such as the condyle, ramus, mandibular body, and symphysis, elucidating alterations in size, volume, and position. However, CT has two main limitations for the primary identification of mandibular asymmetry in growing subjects. Firstly, CT does not fully adhere to the ALARA (As Low As Reasonably Achievable) principle due to the inherent high exposure to ionizing radiation, which poses potential biological risks in pediatric populations [74]. Secondly, CT is not an ideal imaging modality for detailing and characterizing soft tissues. CT primarily excels in imaging dense structures such as bones due to its reliance on X-rays, which are more effectively absorbed by dense materials. Soft tissues, being less dense, may appear less distinct on CT scans, making it challenging to discern detailed features or subtle variations in soft tissue structures. Also, CT is more susceptible to artifacts that compromise the clarity and accuracy of soft tissue representations, impacting the precision of facial soft tissue analysis [21].

Positron Emission Tomography-Computed Tomography (PET-CT) and Single Photon Emission Computed Tomography (SPECT) are imaging modalities that involve the injection of a radiopharmaceutical tracer which accumulates in areas with increased metabolic activity, such as regions of high cell turnover, inflammation and metabolism. Both imaging systems evaluate the dynamic aspects of mandibular asymmetry which could be crucial for differentiating between developmental asymmetries and acquired asymmetries due to trauma or pathological conditions. However, both methods also have limitations, including lower spatial resolution compared to anatomical imaging modalities like CT [21] or MRI [40]. In this regard, three studies [41–43] reported that SPECT is not sufficient to achieve the diagnosis of mandibular asymmetry and should be employed in conjunction with other imaging techniques to provide a more comprehensive assessment of mandibular asymmetry. These findings, again, arise concern related to adherence to the ALARA principle, as the use of multiple imaging modalities may increase radiation exposure.

4.5 CBCT

Although CBCT generates higher radiation exposure compared to single conventional 2D radiographic examinations (OPT, PA), the radiation dose is lower than all additional radiographic examinations necessary for complete orthodontic records, with the advantage of providing more detailed diagnostic data on asymmetry [82, 83]. The American Academy of Oral and Maxillofacial Radiology and the SedentexCT guidelines recommend using CT scans to evaluate facial asymmetry [84, 85]. Moreover, with technological progress, it is possible to reduce the Field of View (FOV) of the CBCT and consequently reduce the amount of radiation. For this reason, most of the studies available in the literature addressing mandibular asymmetry are related to the usage of CBCT technology.

Several studies [54–56, 86] have confirmed a high degree of repeatability of CBCT for assessing asymmetry, achieving good diagnostic outcomes. However, the conclusions drawn from the studies were only based on 2D linear and/or angular measurements of the mandibular, ramus, and condyle. The problem of using 2D measurements of 3D dataset has been recently emphasized since linear measurements can underestimate the true diameter of any curved surface [18, 87]. In this regard, the concept of integrating volumetric data with surface analysis obtained from sophisticated 3D imaging systems has been introduced for analyzing 3D dataset from both quantitative and qualitative perspective [18, 58]. In particular, recent studies [18, 61, 62, 88] demonstrated that reverse engineering software enables a detailed assessment or the monitoring of treatment progress of morphological symmetry of any anatomical structure. Specifically, 3D bone structures derived from CBCT scans can be mirrored and overlaid, allowing for the measurement of Euclidean distances or root mean squared (RMS) differences between the surfaces of the anatomical structures [50]. The mirroring process is performed after identifying the anatomical plane that serves as a reference for the models' speculation. Subsequently, the models are registered using a "Best-fit alignment" algorithm, and a surface analysis is performed and visualized with a color map that highlights differences between both anatomical sides (right-to-left or left-to-right) [18]. Different levels of tolerance are applied through a technique known as "surface-to-surface" analysis, facilitating the identification and characterization of asymmetries with precision.

4.6 Acute and chronic TMJ disorders and asymmetry

Disorders of the temporomandibular joint (TMJ) can be transient or chronic. Acute illnesses are transient and usually go away on their own or with little medical intervention. Treatment for chronic diseases might be more complicated and have a longer duration. Symptoms of TMD (temporomandibular joint disorder) can include pain, jaw dysfunction, and joint noises. Another acute condition could be trauma of TMJ, which could be seen through OPT firstly, but for a better imaging evaluation CT or MRI is recommended [40].

With a female-to-male ratio of 3–6:1, juvenile idiopathic arthritis (JIA) refers to a set of disorders characterized by joint inflammation (arthritis) [53]. A tiny, asymmetrical, and hypoplastic mandible, a skeletal open bite, a short mandibular ramus, an elevated gonial angle, and anterior facial convexity are among the classic indicators of inflammation present in the affected joints. It has been suggested that the primary underlying causes of maxillomandibular growth abnormalities are chronic inflammation and gradual disruption of the condylar cartilage during mandible development. Affected condyles have a shorter and frequently asymmetric mandibular ramus [89]. Patients with JIA frequently exhibit indications of erosion and flattening of the condylar head, varying in severity. There are differences in the degree of functional limitations according to how much of the condylar head has been affected by the articular injury, ranging from minor erosions and osteophytes to conditions in which the condylar head is completely absent [53]. Using two-dimensional (2D) cephalometric studies, dentofacial development deviation in JIA with TMJ involvement has been well-described [90]. However, compared to 2D methods, 3D imaging offers a better visibility of dentofacial features [91]. Over the past 20 years, 3D imaging techniques have become more common in the assessment and follow-up of dentofacial development deviation due to the advent of cone-beam computed tomography (CBCT) in the field of dentistry [53].

Moreover, the diagnosis and follow up of TMJ chronic disorder such as internal derangement could be done with MRI, with no biological side effect into the patient.

4.7 Clinical implications

In light of the findings retrieved from the included studies, pediatric dentists and orthodontists should follow an appropriate clinical strategy when using radiological tools for the diagnosis of mandibular asymmetry. In this regard, after clinical facial and occlusal examination, a preliminary detailed analysis of 2D data retrieved from OPT is necessary to discriminate potential signs of asymmetry and to identify the area/regions involved. CBCT scans are encouraged as a second level of investigation, due to several advantages: (1) the ability to perform measurements in the three dimensions in each investigated area, (2) obtain volumetric reconstruction and volumetric data for side-to-side comparison, (3) integrate volumetric data with the analysis of side-to-side surface dataset, aiding in distinguishing the area mostly involved by the developing asymmetry. PET-CT and SPECT should only be considered if active pathological conditions are suspected.

The results discussed in this narrative are based on a limited number of studies, with heterogenous methodological design. In this regard, the topic of diagnosing mandibular asymmetry appears to be underestimated in literature. Future studies are warmly encouraged to evaluate and compare the diagnostic effectiveness of different radiographic imaging systems for detecting different mandibular asymmetric conditions.

5. Conclusions

According to current knowledge, there is no unanimous consensus on the method for diagnosing mandibular asymmetries. The objective of this literature review is, therefore, to provide a practical guide for clinicians to easily diagnose this condition. CBCT appears to be the preferred examination method, thanks to the assessment of a 3D structure with a 3D image. However, clinicians should consider the biological cost, namely the radiation exposure rate to which a young patient would be subjected. Therefore, in cases of mild asymmetries, the use of only orthopantomography might be advisable as a primary diagnostic tool in children.

AVAILABILITY OF DATA AND MATERIALS

The data of the present manuscript are available upon request to the corresponding author.

AUTHOR CONTRIBUTIONS

VR—formal analysis; SLR—wrote the manuscript and performed the research; MC—visualization; RL—provided help and advice; ALG—designed the research study and made revision. All authors contributed to editorial changes in the manuscript. All authors read and approved the final manuscript.

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CONFLICT OF INTEREST

The authors declare no conflict of interest. Antonino Lo Giudice is serving as one of the Editorial Board members of this journal. We declare that Antonino Lo Giudice had no involvement in the peer review of this article and has no access to information regarding its peer review. Full responsibility for the editorial process for this article was delegated to NM.

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