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Systematic Review

The use of magnetic resonance imaging in the diagnosis of unilocular radiolucent images of the jawbone: a systematic review of the literature

Olfa Zaghden[1,*], Timothé Debré[2], Thien Huong Nguyen[3], Lucas Duong[2], François Ferré[2]

[1] Department of Oral Radiology, University Dental Clinic, Monastir University, Monastir, Tunisia
[2] Dental Department, Charles Foix Hospital, AP-HP, 94200 Ivry Sur Seine, France
[3] Department of Neuro Imaging, C.H.N.O. des Quinze-Vingts, Paris, France

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Abstract – Introduction: Magnetic Resonance Imaging (MRI) is a recent and non-irradiating imaging technique allowing an optimal analysis of soft tissues. The goal of this review was to investigate the contribution of MRI in differentiating benign lesions of the jawbone presenting with the same appearance (radiolucent image) on panoramic radiograph, CT scan, or Cone Beam Computed Tomography (CBCT). **Materials and methods:** A literature review was performed on Medline and Embase. The MeSH keyword indexing language was used. The following keywords have been used. (Magnetic Resonance Imaging) AND ((odontogenic tumors) OR (ameloblastoma) OR (Cementoma) OR (odontogenic cyst, calcifying) OR (odontogenic tumor, squamous) OR (Odontoma) OR (Odontogenic cysts) OR (Basal cell nevus syndrome) OR (dentigerous cyst) OR (Odontogenic cyst, Calcifying) OR (Periodontal cyst)). This review was completed by a manual search in the bibliography of the selected articles. **Results:** A total of 220 articles were identified. After applying the non-inclusion criteria, 35 articles were retained for reading. After reading, 24 articles were included in data synthesis. MRI sequences including T1 weighted (T1w), T2 weighted (T2w) postcontrast T1 weighted with fat saturation (T1wFS+C) and diffusion-weighted images (DWI) may allow the operator to differentiate a cystic process from a tumor process. MRI can identify dentigerous cysts (DCs), inflammatory cysts, odontogenic keratocysts (OKs), or other unusual lesions, such as ameloblastoma (AB). A list of diagnostic criteria can therefore allow a more detailed analysis compared to CT or CBCT and establish a more accurate presumptive diagnosis. **Discussion:** MRI can allow a more precise orientation compared to CT scan analysis. The signal homogeneity on T1w and T2w, the postcontrast enhancement and the apparent diffusion coefficient are the three main parameters to be studied in order to make an accurate presumptive diagnosis. **Conclusion:** Based on this review, it can be concluded that the inclusion of MRI in the diagnosis process for unilocular radiolucent jaw lesions is beneficial for distinguishing between cystic and tumor process.

Introduction

In the field of orofacial radiology, the accurate diagnosis of bone lesions represents a clinical challenge [1]. Historically, this task has relied heavily on conventional imaging modalities, such as cone-beam computed tomography (CBCT) and computed tomography (CT). However, these examinations show their limits in the differentiation of a cystic process from a benin tumour process [2].

The fact that radiolucent features are the most frequently encountered type in the assessment of jawbone pathologies is of particular interest in our case [3]. Their ubiquity underscores the urgent need for improved diagnostic precision in this domain. While Magnetic Resonance Imaging (MRI) has, over the years, emerged as an indispensable tool for soft tissue assessment throughout the orofacial region, its indication in evaluating bone lesions remains largely unappreciated by surgeons. The prevailing practice leans towards employing MRI primarily for the diagnosis of soft tissue pathologies [4,5], such as salivary gland tumors [6], neurogenic lesions [7,8], and temporomandibular joint disorders [9], while reserving CBCT and CT for bone-related concerns.

MRI stands out for its unique ability to capture the complex nuances of tissue characterization through multiple sequences. This distinguishing feature makes MRI a potentially game-changing tool in the search for the true nature of radiolucent

* Correspondence: olfazaghden94@gmail.com

unilocular lesions of the jawbone [10,11]. By exploiting its ability to explore tissue composition, MRI promises to differentiate between tumors and cysts that often present with similar radiographic presentations on CBCT or CT scan [12].

In light of these considerations, our central goal in this paper was to conduct a systematic review of the existing literature. Through this review, we aimed to shed light on the potential contributions of MRI in enhancing the diagnostic precision of unilocular radiolucent lesions of the jawbone.

Our second objective was to establish a list of criteria, depending on the lesion and MRI type, allowing the reading of MRI to give more precise diagnostic hypotheses than those provided by CBCT or CT scan.

Materials and methods

This systematic review was conducted according to the Preferred Reporting Items for Systematic Reviews and Meta Analysis (PRISMA) criteria [13].

Focused question

Can conventional or functional MRI provide more accurate diagnostic hypotheses than CBCT or CT for unilocular radiolucent lesions of the jawbone?

Study design

The acronym Population, Interventions, Comparisons and Outcomes (PICO) was used to define the problem and ask the question that the study would like to answer on [14].

Population: Patient with a unilocular radiolucent image of the mandible or maxilla.

Interventions: Conventional or diffusion MRI.

Comparisons: Conventional or diffusion MRI of others lesions.

Outcomes: Signal homogeneity and intensity in the different MRI sequences studied. ADC values on diffusion-weighted MRI.

Search strategy: An exhaustive search of the literature was conducted from January 2000 to December 2020. The electronic search was performed on Medline® (PubMed) and Embase® (Elsevier) Databases. A hand search was also conducted on the eminent reviews and their References.

Search terms: The following search terms were used as keywords (or MeSH).

- "Magnetic Resonance Imaging" [MESH]
- "Odontogenic tumors" [MESH]
- "Ameloblastoma" [MESH]
- "Cementoma" [MESH]
- "Odontogenic cysts, calcifying" [MESH]
- "Odontogenic tumors, squamous" [MESH]
- "Odontoma "[MESH]
- "Odontogenic cysts" [MESH]
- "Basal cell nevus syndrome" [MESH]
- "Dentigerous cyst" [MESH]
- "Periodontal cyst" [MESH].

Using the Boolean operators <AND> and <OR>, the following equation was formulated:

"(Magnetic Resonance Imaging) AND ((odontogenic tumors) OR (ameloblastoma) OR (Cementoma) OR (odontogenic cyst, calcifying) OR (odontogenic tumor, squamous) OR (Odontoma) OR (Odontogenic cysts) OR (Basal cell nevus syndrome) OR (dentigerous cyst) OR (Odontogenic cyst, Calcifying) OR (Periodontal cyst))".

Eligibility criteria

- Inclusion criteria:

All articles meeting one the following study patterns were included:

- Prospective cohort study
- Retrospective cohort study
- Case series
- Article published from the 2000s
- Article written in English or French
- Article investigating the use of MRI in the diagnosis of benign tumors or cysts of the jawbone

- Non-inclusion criteria:

All the items meeting at least one of these criteria were not included:

- Thesis
- Case study
- Literature review
- Meta-analysis.

Selection of studies

All the members of the working group contributed to the elaboration of the systematic review through research, article selection, reading, critical evaluation of the selection as well as the data extraction. In case of disagreement concerning the integration of a data, a group discussion was conducted in order to reach a consensus.

The studies included provided detailed information regarding the final histological diagnosis of the lesions.

Data collection and extraction process

Two evaluators (OZ and TD) performed data extraction independently using a spreadsheet specially created to extract the necessary information including the following items: number of patients studied, types of lesions studied, type of MRI used and study conclusion.

Bias risk assessment in included studies

Bias risk assessment was assessed independently by two reviewers (OZ and TD) using the Joanna Briggs Institute (JBI) critical appraisal tool, specifically the checklist for diagnostic

test accuracy [15]. The checklist is a 10-item appraisal consisting of the following areas: (1) randomization component, (2) avoidance of case control, (3) inappropriate participant exclusion, (4) index test interpretation, (5) threshold specification, (6) reference standard validity, (7) reference standard interpretation, (8) Temporal Synchronization, (9) Reference standard uniformity, and (10) Participants inclusion in the analysis. These items were scored either "yes", "no", "unclear", or "not applicable". Two reviewers (OZ and TD) independently scored the retained studies with discrepancies managed through discussion. In cases where disagreements remained unresolved after discussion, a third author (FF) was involved to facilitate and reach a final consensus.

Three levels were determined [15]:

- High risk of bias: "yes" scores below 49%.
- Moderate risk of bias: "yes" scores between 50% and 69%.
- Low risk of bias: "yes" scores higher than 70%.

Results

Search results

A total of 215 items were pre-selected from Medline® and Embase® databases and five items were pre-selected through a manual search of the bibliography of the selected articles.

After applying the non-inclusion criteria, 35 items were retained for reading and evaluated in full text for eligibility. After reading, 11 articles were excluded and 24 were included in data synthesis.

The PRISMA© flow chart is presented in Figure 1.

Study selection

The included studies underwent an assessment of their methodological quality, as depicted in (Tab. I). Out of these, 11 studies exhibited a moderate level of bias [16,18,19,21,22,24,25,30,34–36], six studies had a low level of bias [11,17,20,32,33,38] while seven items had a high score of bias [23,26–29,31,37,]. The overall bias score ranged from 30% to 80%.

Characteristics of included studies

The characteristic features of eligible studies are summarized in Table II. The time span assessed in the studies ranged from 2001 to 2020. Of these included studies, 13 were retrospective [16,23–27,29–31,33,34,36,37], 9 prospective [11,17–19, 20,21,28,32,38] and only 2 case series [22,35]. The majority of studies included in the review assessed the features of radiolucent lesions on conventional MRI and only 8 studies focused on diffusion MRI.

Synthesis of results

Data synthesis was based on two criteria: the first is the type of MRI used and the second is the lesion studied.

Out of the 24 selected papers, the radiological aspect of Odontogenic Keratocyst (OK) is described in 11 reports, the characteristics of Conventional ameloblastoma (CA) is studied in 10 items, and Dentigerous Cyst (DC) is investigated in 8 items. The utility of MRI in the diagnosis of unicystic ameloblastoma (UA) is highlighted in 7 studies. A total of 6 studies focused on radicular cyst (RC) and apical granuloma (AG). Simple bone cyst (SBC), nasopalatine duct cyst (NPDC), odontogenic myxoma (OM), and the use of conventional MRI in the diagnosis of adenomatoid odontogenic tumors (AOT) are reported in 5,3,3, and 2 articles, respectively.

- Conventional MRI
  - Odontogenic keratocyst (OK)

    The characteristics of OK when observed through conventional MRI have been extensively examined in 11 reports. These findings reveal a wide spectrum of signal intensity (SI) spanning from low to high on T1w images [11,17, 21,24,26,28,32,33,36]. Furthermore, it is reported that OK often shows heterogeneous T2w high SI on 7 of the selected items [11,17,21,24,28,33,36]. On postcontrast T1w with fat saturation (T1wFS+C), a thin rim-enhancement (<3 mm) is observed while the intraluminal contents remain unenhanced [11,21,24,28, 32,33]. However, a thick wall (>3 mm) is observed in 30% of cases [11].

  - Conventional ameloblastoma (CA)

    CA is investigated in 10 studies, showing its characteristic presentation as a lesion with a mixture of solid and cystic portions. On T1w, cystic portions of CA are reported to display varying signal intensities including low [28,32], intermediate [28,32], or variable range from low to high [21,34]. Solid Portions are described as having low SI [23,28,33]. On T2w, all authors confirm that cystic portions present a more intense hypersignal than solid portions [21,23,26,28,30,32–34]. Some researchers highlight that T2 sequences enable a more accurate differentiation between cystic and solid portions [28,32]. Moreover, the investigation into the aspects of ameloblastoma on contrast-enhanced MRI by some authors reveals that Gadolinium injection can result in homogeneous enhancement of solid portions while only the periphery of cystic portions is enhanced [28].

  - Unicystic ameloblastoma (UA)

    Six studies have explored unicystic ameloblastoma, which typically appears as a well-defined, unilocular lesion on conventional MRI. On T1w, an intermediate signal is commonly observed in the majority of cases [27,34] and SI tends to be high on T2w. [11,21,27,33,34]. Some authors have additionally noted thick enhancement of the cystic wall [27,30,33,34] and the presence of an intraluminal nodule attached to the solid wall.

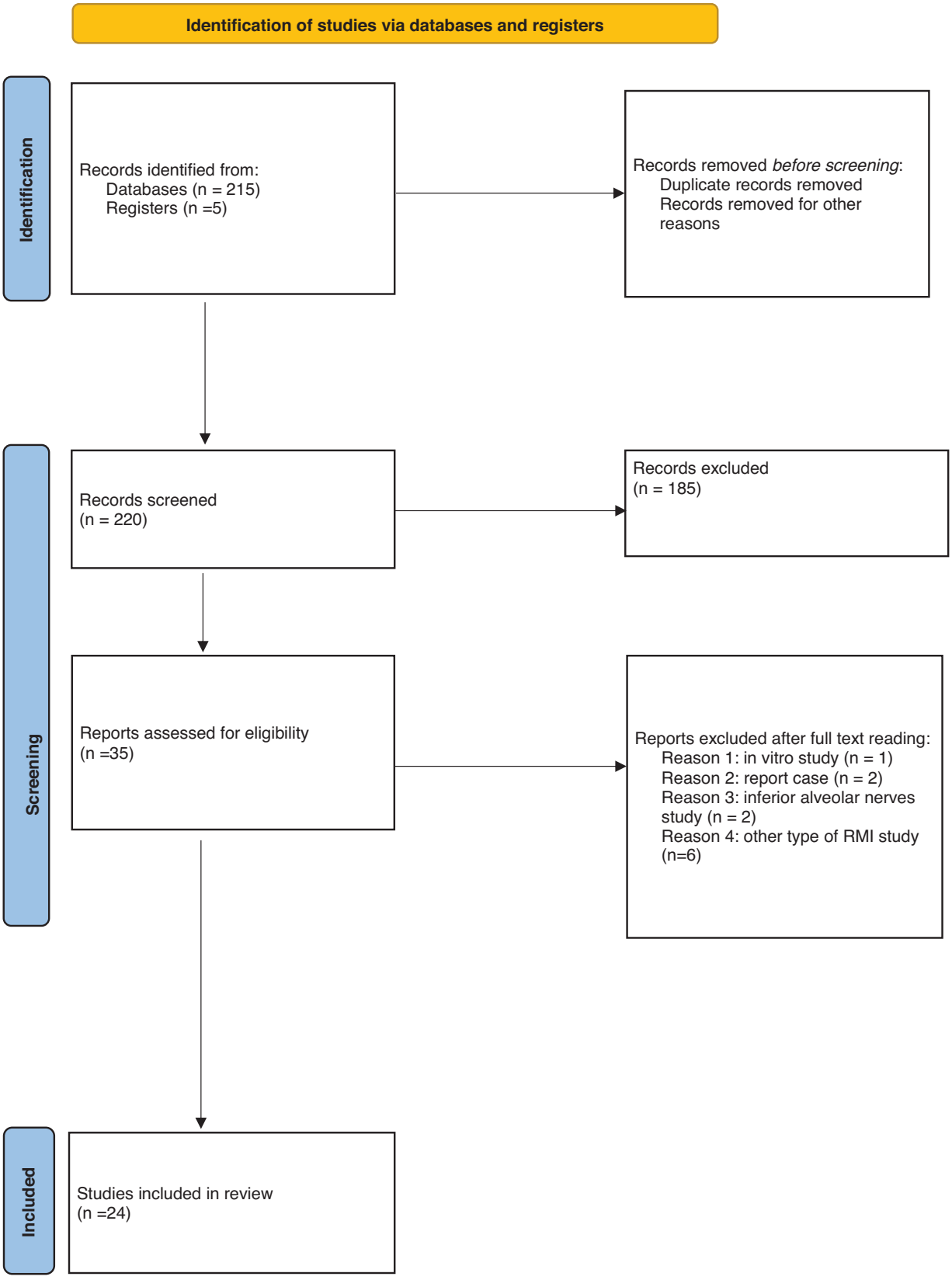

Fig. 1. Flow chart of literature search.

Table I. Quality scoring of the retained articles according to JBI critical appraisal checklist.

Author and year	1	2	3	4	5	6	7	8	9	10	Score	Risk of bias
Vanagundi R, *et al. 2020* [11]	N	N	Y	Y	Y	Y	Y	U	Y	Y	**7**	Low
Baba A, *et al. 2020* [16]	N	N	Y	Y	NA	Y	Y	U	Y	Y	**6**	Moderate
Ogura I *et al. 2019* [17]	N	Y	Y	Y	Y	Y	Y	U	Y	Y	**8**	Low
Oda T, *et al. 2018* [18]	N	Y	Y	Y	NA	Y	U	U	Y	Y	**6**	Moderate
Juerchott A, *et al. 2018* [19]	N	Y	Y	Y	NA	Y	U	U	Y	Y	**6**	Moderate
Lizio G, *et al. 2018* [20]	N	Y	Y	Y	N	Y	Y	U	Y	Y	**7**	Low
Han Y, *et al. 2018* [21]	N	Y	Y	Y	NA	N	U	U	Y	Y	**5**	Moderate
Geibel MA *et al. 2017* [22]	Y	Y	Y	Y	NA	Y	U	U	N	Y	**6**	Moderate
Apajalahti S, *et al. 2015* [23]	N	N	Y	N	NA	Y	U	U	Y	Y	**4**	High
Probst FA*, et al. 2015* [24]	Y	N	Y	Y	NA	Y	U	U	Y	Y	**6**	Moderate
Kheir E, *et al.* 2013 [25]	Y	N	Y	N	NA	Y	U	U	Y	Y	**5**	Moderate
Fujita M, *et al.* 2013 [26]	N	N	Y	N	NA	Y	U	U	Y	Y	**4**	High
Cassetta M, *et al.* 2012 [27]	N	N	Y	U	NA	N	U	U	Y	Y	**3**	High
Srinivasan K, et a. 2012 [28]	Y	Y	N	U	NA	N	U	U	Y	Y	**4**	High
Eida S, *et al.* 2012 [29]	N	N	N	U	Y	Y	U	U	Y	Y	**4**	High
Hisatomi M, *et al.* 2011 [30]	N	Y	Y	N	NA	Y	U	U	Y	Y	**5**	Moderate
Yanagi Y, *et al.* 2010 [31]	N	Y	Y	N	NA	Y	U	U	N	Y	**4**	High
Sumi M, *et al.* 2008 [32]	Y	Y	Y	Y	NA	Y	U	U	Y	Y	**7**	Low
Konouchi H, *et al.* 2006 [33]	N	Y	Y	Y	NA	Y	Y	U	Y	Y	**7**	Low
Asaumi J, *et al.* 2005 [34]	N	Y	Y	N	NA	Y	U	U	Y	Y	**5**	Moderate
Asaumi J, *et al.* 2004 [35]	N	Y	Y	N	NA	Y	N	U	Y	Y	**5**	Moderate
Hisatomi M, *et al.* 2003 [36]	N	Y	Y	U	NA	Y	U	U	Y	Y	**5**	Moderate
Matsuzaki M, *et al.* 2003 [37]	N	N	Y	N	NA	Y	U	U	N	Y	**3**	High
Eriksson l, *et al.* 2001 [38]	N	Y	Y	Y	NA	Y	U	Y	Y	Y	**7**	Low

JBI: Joanna Briggs Institute, **N:** No, **NA:** Not Applied, **U:** Unclear, **Y:** Yes.

- Dentigerous Cyst (DC)

The aspect of DC on conventional MRI has been analyzed in 7 reports. According to these selected studies, DC presents a lesion with homogeneous signal with variable SI on T1w, which can be low [28,33], intermediate [27,36], high [17], or ranging from low to high [11,21]. Meanwhile, on T2w, it shows a homogeneous and high signal [11,17,21,27,28,33,36]. Furthermore contrast-enhanced images, illustrate a thin rim-enhancement (<3 mm) [11].

- Apical granulomas (AG) and radicular cysts (RC)

When it comes to AG and RC, both investigated, via conventional MRI, including T1w, T2w, fat-saturated T1-weighted (T1wFS) images, fat-saturated T2-weighted images (T2wFS), and T1wFS+C, in five reports.

AG is defined as a blurred image with unclear margin, and low SI on both T1w and T2w [20,22], with an inhomogeneous and thick periphery on T1wFS+C and an inhomogeneous center on T2w. The lesion also involves surrounding tissue on T1wFS+C and T2wFS [19]. Conversely, RC is presented as a well-delineated lesion, with low-intermediate SI on T1w, high SI on T2w, and thin rim-enhancement on contrast-enhanced images [19,20,22,36], having no impact on the adjacent medullary bone [19]. The signal is classically homogeneous [17,19,20,22,36], although two cases of RC are described as heterogeneous [36].

- Simple bone cyst (SBC)

The characteristics of SBC on conventional MRI have been investigated in four articles. According to these selected studies, SBC is defined as a well-delimited lesion with homogenous low/intermediate signal on T1Ww and homogenous high signal on T2Ww [17,29,31,37]. According to Suomalainen, contrast injection allows thin rim-enhancement [39].

- Nasopalatine duct cyst (NPDC)

According to the two selected studies, NPDC is defined as a well-delimited image with high SI on both T1w and T2w on conventional MRI [17,36]. The high SI on T1w is explained by the keratin-rich and viscous fluid content [36].

Table II. List of items included in the review.

	Title	Author	Year	Studied lesion	Studied sequences
1	Diffusion-weighted magnetic resonance imaging in the characterization of odontogenic cysts and tumors	Vanagundi R, *et al.* [11]	2020	–Odontogenic keratocyst (17) – Unicystic ameloblastoma (5) – Dentigerous cyst (5)	T1 T2 T1 FS STIR Diffusion
2	Desmoplastic ameloblastoma of the jaw: CT and MR imaging findings	Baba A, *et al.*[16]	2020	Conventional ameloblastoma (6)	T1 T2 T1FS+C
3	Diffusion-weighted magnetic resonance imaging in odontogenic keratocysts: preliminary study on usefulness of apparent diffusion coefficient maps for characterization of normal structures and lesions	Ogura I *et al.* [17]	2019	– Radicular cysts (3) – Odontogenic keratocyst 5) – Nasopalatine duct cyst (3) – Dentigerous cyst (4) – Simple bone cyst (1)	T1 T2 STIR Diffusion
4	Diffusion-weighted magnetic resonance imaging in oral and maxillofacial lesions: preliminary study on diagnostic ability of apparent diffusion coefficient maps	Oda T, *et al.* [18]	2018	Odontogenic keratocyst (4) Nasopalatine duct cyst (2)	T1 T2 Diffusion
5	Differentiation of periapical granulomas and cysts by using dental MRI: a pilot study	Juerchott A, *et al.* [19]	2018	Radicular cysts (5) Apical granulomas (6)	T1 T2 T1FS T2FS T1FS+C
6	Differential diagnosis between a granuloma and radicular cyst: effectiveness of magnetic resonance imaging	Lizio G, *et al.* [20]	2018	Radicular cysts and apical granuloma (34)	T1FS+C
7	Diffusion-weighted MR imaging of unicystic odontogenic tumors for differentiation of unicystic ameloblastomas from keratocystic odontogenic tumors	Han Y, *et al.* [21]	2018	Unicystic ameloblastoma (11) Odontogenic keratocyst (15) Conventional ameloblastoma (11) Dentigerous cyst (3)	T1 T2 T1FS+C T2FS Diffusion
8	Characterization of apical bone lesions: Comparison of MRI and CBCT with histological findings – a case series	Geibel MA *et al.* [22]	2017	Radicular cysts (13) Apical granuloma (2)	T1 T2
9	Imaging characteristics of ameloblastomas and diagnostic value of computed tomography and magnetic resonance imaging in a series of 26 patients	Apajalahti S, *et al.* [23]	2015	Conventional Ameloblastoma (5)	T1 T2 T1FS+C
10	Magnetic resonance imaging: a useful tool to distinguish between keratocystic odontogenic tumours and odontogenic cysts	Probst FA, *et al.* [24]	2014	Odontogenic Keratocyst (10) Odontogenic cysts (10)	T1 T2 STIR T1FS+C
11	The imaging characteristics of odontogenic myxoma and a comparison of three different imaging modalities	Kheir E, *et al.* [25]	2013	Odontogenic myxoma (10)	T1 T2 T1FS+C
12	Diagnostic value of MRI for odontogenic tumors	Fujita M, *et al.* [26]	2013		T1 T2 STIR DCE-MRI

Table II. (continued).

	Title	Author	Year	Studied lesion	Studied sequences
				Conventional Ameloblastoma (26) Odontogenic keratocyst (14) Adenomatoid odontogenic tumor (3) Odontogenic myxoma (4) Odontogenic fibroma (2)	
13	The use of high resolution magnetic resonance on 3.0-T system in the diagnosis and surgical planning of intraosseous lesions of the jaws: preliminary results of a retrospective study	Cassetta M, *et al.* [27]	2012	Dentigerous cyst (8) Unicystic ameloblastoma (1) Conventional amelobastoma (1)	T1 T2 T1+C T2FS
14	Diffusion-weighted imaging in the evaluation of odontogenic cysts and tumors	Srinivasan K, *et al.* [28]	2012	Conventional ameloblastoma (10) Odontogenic keratocyst (5) Dentigerous cyst (2) Odontogenic myxoma (3)	T1 T2 Diffusion
15	Apparent diffusion coefficient-based differentiation of cystic lesions of the mandible	Eida S, *et al.* [29]	2012	Simple Bone Cyst (4) Ameloblastoma (5) Dentigerous cyst (9) Odontogenic keratocyst (5) Radicular cyst (4)	T1 T2FS T1+C Diffusion
16	Diagnostic value of dynamic contrast-enhanced MRI for unilocular cystic-type ameloblastomas with homogeneously bright high signal intensity on T2-weighted or STIR MR images	Hisatomi M, *et al.* [30]	2011	Conventional amelobastoma (9) Unicystic ameloblastoma (3)	T1 T2 T1FS+C STIR
17	Usefulness of MRI and dynamic contrast-enhanced MRI for differential diagnosis of simple bone cysts from true cysts in the jaw	Yanagi Y, *et al.* [31]	2010	Simple bone cyst (10)	T1 T2 DCE-MRI
18	Diffusion-weighted MR imaging of ameloblastomas and keratocystic odontogenic tumors: differentiation by apparent diffusion coefficients of cystic lesions	Sumi M, *et al.* [32]	2008	Conventional ameloblastoma (9) Odontogenic keratocyst (7)	T1 T2 T1FS Diffusion
19	Usefulness of contrast enhanced MRI in the diagnosis of unicystic ameloblastoma	Konouchi H, *et al.* [33]	2006	Unicystic ameloblastoma (3) Conventional ameloblastoma (4) Odontogenic keratocyst (4) Dentigerous cyst (3)	T1 T2 T1FS+C
20	Assessment of ameloblastomas using MRI and dynamic contrast-enhanced MRI	Asaumi J, *et al.* [34]	2005	Conventional amelobastoma (6) Unicystic ameloblastoma (2)	T1 T2 T1FS+C
21	Assessment of **MRI** and dynamic contrast-enhanced **MRI** in the differential diagnosis of adenomatoid odontogenic tumor	Asaumi J, *et al.* [35]	2004	Adenomatoid odontogenic tumor (3)	T1 T2 T1FS+C
22	MR imaging of epithelial cysts of the oral and maxillofacial region	Hisatomi M, *et al.* [36]	2003	Odontogenic Keratocyst (7) Dentigerous cyst (3) Radicular cyst (10) Nasopalatine duct cyst (4)	T1 T2 T1FS+C
23	MR imaging in the assessment of a solitary bone cyst	Matsuzaki M, *et al.* [37]	2003	Simple bone cyst (9)	T1 T2FS DCE-MRI T1+C

Table II. (continued).

	Title	Author	Year	Studied lesion	Studied sequences
24	Simple bone cyst: A discrepancy between magnetic resonance imaging and surgical observations	Eriksson L, *et al.* [38]	2001	Simple bone cyst (7)	T1 T2 Diffusion

STIR: Short T1 Inversion Recovery; FS: Fat saturation; DCE-MRI: Dynamic contrast-enhanced MRI.

- Odontogenic myxoma (OM)

  According to the three selected studies, OM presents as a mixture of myxoid and collagenous portions when visualized through MRI [25,26,28]. It seems to be well- or moderately-defined and it shows low to intermediate SI on T1w and high SI on T2w [25,28]. The signal is considered inhomogeneous [25]. Contrast-enhanced images prove valuable in distinguishing myxoid and collagenous matrices. Indeed, post-contrast T1w shows poorly defined lesions with heterogeneous enhancement. In fact, the myxoid portions remain unenhanced, contrarily to the collagenous portions [25,26,28].

- Adenomatoid odontogenic tumor (AOT)

  Finally the use of MRI in the diagnosis of AOT is explored in two studies [26,35]. When the tumor is small, it shows low SI on T1w and slight high SI on T2w. The administration of contrast medium leads to homogeneous enhancement of the entire lesion. Conversely, when the tumor size is larger, it becomes partitioned and the presence of microcysts is noted. In such instances contrast medium injection results in an inhomogeneous enhancement pattern, corresponding primarily to the solid portions of the lesion.

- Diffusion MRI:
  - Odontogenic Keratocyst

    The exploration of diffusion-weighted MRI in diagnosing of OK has been investigated in 7 reports. The Apparent Diffusion Coefficient (ADC) of OK varies from one author to another and it ranges from 0.87×10^{-3} mm^2/s [29], to 1.582×10^{-3} mm^2/s [11].

  - Conventional Ameloblastoma

    CA, as described in three studies, demonstrates distinctive diffusion characteristics, with solid portions displaying restricted diffusion and cystic portions exhibiting free diffusion. The aforementioned three reports a mean ADC of about 2×10^{-3} mm^2/s for cystic portions [21,28,32] and of about $1. \times 10^{-3}$ mm^2/s for solid portions [21,28,32].

  - Unicystic Ameloblastoma

    UA, in the three selected items, shows free diffusion with an ADC similar to that found for the cystic portions of CAs, exceeding 2×10^{-3} mm^2/s [11,21,29].

  - Dentigerous Cyst

    Diffusion MRI findings for DC are highlighted in five reports. As for DC, the findings are inconsistent. Some lesions display free diffusion [11] while others express restricted diffusion [21,28]. Additionally ADC values of DC varied widely, ranging from 1.23×10^{-3} mm^2/s [28] to 2.150×10^{-3} mm^2/s [11].

  - Radicular Cyst

    The ADC of RC is measured in two studies. In a cohort of 3 lesions, Ogura *et al.* reported an average of $1.82 \pm 0.71 \times 10^{-3}$ mm^2/s while Eida *et al.* reported an average of $0.9 \pm 0.21 \times 10^{-3}$ mm^2/s in 4 patients [17,29].

  - Simple bone cyst

    The measurement of the ADC values for SBC is reported in three studies. Ogura *et al.* reported a value of 2.74×10^{-3} mm^2/s in one patient [17], Eida *et al.* obtained an average of 2.52×10^{-3} mm^2/s in 4 patients [29], and Eriksson *et al.* reported a value of 2.7×10^{-3} mm^2/s in one patient [38]. Those selected consistently indicate free diffusion, aligning with the lesion's histological characteristics.

  - Naso-palatine duct cyst

    Diffusion imaging in diagnosing NPDC is investigated in two articles. In a cohort of three patients, Ogura *et al.* reported a mean of 2.28×10^{-3} mm^2/s [17] while Oda *et al.* reported a mean of 2.34×10^{-3} mm^2/s in two patients[18].

  - Odontogenic Myxoma

    Regarding OM, ADC evaluation is available in a single paper among the included items. In this study, the reported average ADC value was 2.09×10^{-3} mm^2/s for three patients [28].

Discussion

The present systematic review includes 24 items investigating the potential contributions of MRI in enhancing the diagnostic precision of unilocular radiolucent lesions of the jawbone.

Diffusion Weighted Imaging (DWI) stands out as a valuable imaging technique for delineating radiolucent lesions within the maxillomandibular region, as supported by references [11,21,28,29]. Additionally, ADC maps have demonstrated their utility as a supplementary tool for characterizing normal structures and cystic lesions in the jaw, as evidenced by references [17,18,32]. On the other hand, the usefulness of conventional MRI in differentiating between these entities remains controversial. According to some authors it seems to play a minor role in the characterization of these lesions which present overlapping morphologic features [11,26]. Conversely, other experts have emphasized the value of contrast-enhanced MRI for diagnosing UA [33] and distinguishing OK from odontogenic cysts [26].

Conventional MRI

Odontogenic keratocysts are characterized by variable SI on T1w, hypersignal on T2w, and thin rim-enhancement on contrast-enhanced images typically less than 3 mm in thickness. However, in about 30% of cases, a thicker wall ($>$ 3 mm) may be observed due to a chronic inflammation and epithelial wall hyperplasia.

The high signal on T1w and the low and more heterogeneous signal on T2w could be explained by the accumulation of keratin and cholesterol crystals within the cystic cavity [33,36]. This MRI appearance can help distinguish OK from other odontogenic cysts and tumors. Studies have shown a substantial difference in signal uniformity on T1w, T2w, and short TI inversion recovery (STIR) weighted images when comparing OKs and ameloblastomas [26].

Conventional ameloblastomas exhibit a distinct enhancement pattern on contrast-enhanced MRI with homogeneous enhancement of solid portions and peripheral enhancement of the cystic portions highlighting the mixed solid and cystic components characteristic of ameloblastomas [28]. In contrast, odontogenic keratocysts typically lack the distinct solid tissue features and show only weak cyst walls enhancement, without the heterogeneous enhancement pattern observed in ameloblastomas.

In summary, the contrast enhancement patterns on MRI can help distinguish ameloblastomas, which show a mixed solid and cystic appearance, from odontogenic keratocysts, which typically lack distinct solid components and show only weak cyst wall enhancement [23,32]

Unicystic Ameloblastomas exhibit an intermediate SI on T1w and a homogeneous high SI on T2w. These MRI features are not significantly different from those of odontogenic cysts, especially DC and OK [11,27,33,34]. Consequently, the majority of studies recommended the use of contrast-enhanced MRI to help distinguish UA from other types of odontogenic cysts. The thick enhancement of the cystic wall [27,30,33,34] and the presence of an intraluminal nodule attached to the solid wall are the two main characteristic MRI features of UA [30,33,34].

A comparative analysis of the MRI features of Radicular Cyst and Apical Granuloma was performed to facilitate their differentiation: Juerchott *et al.* described 15 analytical criteria, six of which were found to be statistically significant in differentiating RC from AG. These criteria encompass four components of a lesion, including the center, the peripheral rim, the margins, and the involvement of the surrounding tissue, with the main analysis criteria is the homogeneity of the signal [19]. In a separate study, Lizio *et al.* reported **6 criteria** to differentiate RC from AG, including SI on T1w, and T2w, the presence/absence of a clear margin, signal homogeneity, the presence/absence of a low intensity outline on both T1WI and T2WI, and the distribution pattern of the contrast agent [20]. Differential diagnosis between RC and AG requires meeting at least 4 of these 6 criteria [20]. Additionally Geibel *et al.* concluded that the signals intensity and homogeneity on T1w and T2w play a role in distinguishing AG from RC [22]. RC presents as a well-delimited homogenous lesion with low SI on T1w, high SI on T2w, and thin rim-enhancement on contrast-enhanced images. In contrast, AG presents as a blurred image with unclear margin, having low SI on both T1w and T2w.

Nonetheless, RC can exhibits heterogeneity in two instances: One due to potential infection from oral cavity communication, and another with no histological rationale, leading to an erroneous diagnosis of OK [36].

The majority of studies suggest that T1wFS+C and T2w sequences are the most accurate for characterizing the content of the lesions and defining their margins, and are therefore useful for distinguishing RC from AG [19,20,22].

When compared to odontogenic cysts, Simple Bone Cyst does not present a notable characteristic on conventional MRI. It presents low SI on T1w, high SI on T2w, homogeneous aspect, and thin rim enhancement after gadolinium injection. This aspect may lead to confusion with OK or DC [31,37]. However, contrast-enhanced T1WI, approximately 6 minutes after the administration of the contrast medium, provides marked enhancement of the margin and slight enhancement of the inner part of the cyst cavity [31,37]. Moreover, dynamic contrast enhanced MRI series show progressive enhancement of the periphery of the cystic cavity towards the interior, indicating progressive exudation of the contrast agent from the surrounding medullary towards the inner part of the lesion [37]. Thus, contrast-enhanced MRI and dynamic MRI are useful in differentiating SBC from other odontogenic cysts.

Lastly, Nasopalatine Duct Cyst show high SI on T1-weighted images. This “specific feature” [36] may help distinguish it from its main differential diagnosis, RC, presenting an intermediate SI on T1w. The high SI on T1w is explained by the keratin-rich and viscous fluid content [36].

The Odontogenic Myxoma and Adenomatoid Odontogenic Tumor, have unique characteristics facilitating their differentiation from other lesions. OM typically displays low-to-intermediate signal on T1w and inhomogeneous high signal on T2w with selective enhancement of collagenous portions on post-contrast T1w [25,26,28].

Conversely, AOT exhibits low signal on T1w and moderate signal on T2w, with complete enhancement upon contrast injection, making it distinguishable from all cystic lesions, including DC and OK [35].

Diffusion MRI

Diffusion-weighted imaging (DWI) is a technique that study the Brownian motion of molecules and is highly sensitive to physiological parameters such as tissue cellularity, nucleus-cytoplasm ratio, and the integrity of cell membranes [40]. The obtained sequences will be used to calculate the apparent diffusion coefficient (ADC) with units in mm^2/s. A low diffusion coefficient will be interpreted as restricted diffusion. Conversely, a high diffusion coefficient will indicate facilitated diffusion. Therefore, the ADC reflects the viscosity of a lesion [41].

Initially, DWI was primarily employed for assessing intracranial conditions like cerebrovascular accidents, trauma, and epilepsy. Nowadays, DWI is extensively utilized for tumor detection, tumor characterization, and distinguishing between neoplastic and non-neoplastic diseases across various organ systems [42]. Wang *et al.* were the first to investigate the role of DWI in examining head and neck lesions, and they discovered that ADC measurements could effectively characterize these lesions [43].

This review revealed substantial variations in the diffusion signal and ADC values and mapping profiles of fluid regions, depending on the specific type of lesion under examination.

Odontogenic Keratocyst exhibit restricted diffusion with low ADC values around 1, [11,17,18,21,28,29,32] attributed to the presence of viscous substances like desquamated keratin and hyaluronic acid within the cyst's cavity [11].

This diffusion pattern contrasts with the mixed restricted and free diffusion seen in ameloblastomas, allowing these two entities to be reliably differentiated using diffusion-weighted MRI [32,28].

In contrast Unicystic Ameloblastoma (UA) presents free diffusion with an ADC exceeding 2. likely due to the slightly proteinaceous cystic fluid of ameloblastomas [21,29,44]

Dentigerous Cyst (DC) show conflicting diffusion profiles, with some exhibiting restricted diffusion due to the higher viscous content [21,28] while others display free diffusion associated with a reduced concentration of glycosaminoglycans [11]. ADC values are similar to odontogenic keratocysts [17,21], leading to an ongoing debate regarding their differentiation using DWI. Conversely, the prevailing consensus in research indicates the possibility of distinguishing DC from ameloblastomas or simple bone cysts using this technique.

Radicular cyst presents variable ADC values due to fluctuations in intraluminal viscosity, similar to odontogenic keratocysts [17,29]. ADC values can fluctuate based on factors such as the cyst's size, location within the body, and the potential presence of superinfection as dental pulp necrosis, lead to the formation of a cystic cavity filled with cell debris, proteins, and intracellular particles, increasing fluid viscosity [45]. While limited studies restrict our understanding, ADC values can effectively discriminate radicular cysts from ameloblastomas and simple bone cysts.

When it comes to Simple Bone Cyst, it presents free diffusion with an overall ADC value of about 2.5, similar to UA [17,29], ruling out differentiation based on ADC mapping profiles alone. However, this mean value differs from those of odontogenic cysts like dentigerous, radicular and Keratocysts indicating DWI's utility in distinguishing SBC from these entities.

Finally Odontogenic Myxoma presents free diffusion with an ADC of 2.019, explained by the abundance of a water-rich myxoid matrix [28] allowing differentiation from keratocysts having restricted diffusion using diffusion MRI.

The overall ADC values and ADC mapping profiles proved effective in distinguishing certain mandibular cystic lesions. However, relying solely on ADC-based criteria was insufficient for distinguishing ameloblastomas from simple bone cysts or differentiating radicular cysts from keratocystic odontogenic tumors. Therefore, it may be necessary to incorporate additional information for a more precise differentiation of these lesions. Conventional MR imaging, as well as CT and traditional radiography, can provide additional insights for more precise differentiation. This highlights the usefulness and interest of multimodal CBCT/MRI registration for benign cystic and tumor lesions of the jawbone. This approach has been used for cerebral radiotherapy [46] and has been studied, only one time, in the field of dento-maxillary imaging [47].

This systematic review had some limitations. First, we note that the patient cohorts studied are of limited size which is related to the rarity of these lesions. Secondly superinfection processes that are relatively frequent in the mouth can modify the appearance of a lesion on MRI and distort the result. In addition, the diffusion technique is subject to significant artefacts, particularly of magnetic susceptibility of dental origin. Moreover, it emerges from these studies that the "smallest" size of the lesions studied, such as AG, is 5mm. It would be interesting to know if the progress in the technological field and the generalization of high field imaging devices will allow a more precise reading of smaller lesions.

Despite these constraints, a set of criteria (Tab. III) is established based on the specific lesion and MRI type, enabling the interpretation of MRI findings and the formulation of accurate diagnostic hypotheses.

Table III. Summary table by lesion studied. (Number of articles concluding to the given signal/total number of articles).

		Conventional MRI		Diffusion MRI	
	T1	T2	T1+C	Apparent diffusion coefficient ($10^3 mm^2/s$)	Diffusion
Radicular cyst	Hyposignal Homogeneous (4/5)	Hypersignal Homogeneous (5/5)	Thin rim-enhancement No enhancement of the cystic lumen	0.9–1.82	Variable (depends on the content of lesion)
Apical granuloma	Hyposignal Inhomogenous (1/3)	Hyposignal Heterogenous (2/3)	Thicker rim enhancement compared to RC No enhancement of the cystic lumen		
Dentigerous Cyst	Widely variable signal	Hypersignal Homogeneous (7/7)	Thin rim-enhancement No enhancement of the cystic lumen	1.23–2.15	Variable (depends on the content of lesion)
Odontogenic keratocyst	Widely variable signal	Hypersignal Heterogenous (7/10)	Thin rim-enhancement No enhancement of the cystic lumen	0.85–1.58	Restricted
Adenomatoid odontogenic tumor	Hyposignal (1/2)	Slight hight signal Heterogenous (2/2)	Small size: enhancement of the whole lesion Large size: inhomogeneous enhancement		
Simple bone cyst	Hypo-isosignal (4/4)	Hypersignal (4/4)	Thin rim-enhancement	2.52–2.74	Free
Nasopalatine duct cyst	Hypersignal (2/2)	Hypersignal (2/2)		2.28–2.34	Free
Unicystic ameloblastoma	Isosignal (4/6)	Hypersignal (6/6)	Thick rim-enhancement Characteristic enhancement of an intraluminal nodule attached to the lining *No enhancement of the lumen		Free
Conventional ameloblastoma	Widely variable signal	Cystic portions: bright hypersignal (7/8) Solid portions: moderate hypersignal (5/8)	*Enhancement of the margins of cystic portions. *Homogenous Enhancement of solid portions.	Cystic portions: 1.94–2.84 Solid portions: 1.04–1.39	Cystic portions: Free Solid portions: restricted
Odontogenic Myxoma	Low-intermediate signal Inhomogenous (2/3)	Hypersignal Inhomogenous (2/3) (Mixture of myxoid portions and collagenous portions.	*Inhomogeneous enhancement: only enhancement of collagenous portions.	2.091	Free

Conclusion

Based on this review, it can be concluded that the inclusion of MRI in the diagnosis process for unilocular radiolucent jaw lesions is beneficial for distinguishing between cystic and tumor process. The assessment of signal homogeneity in T1 and T2 weighting, the scrutiny of the contrast-enhanced images, and the analysis of diffusion sequences emerge as the three main parameters to be studied in order to make an accurate presumptive diagnosis. Particularly the assessment of DWI encompassing ADC values and mapping profiles has demonstrated effectiveness in distinguishing specific cystic lesions.

Although the use of MRI today represents a significant additional cost for a relatively limited benefit, one can be optimistic about the widespread adoption of this technology in the coming decades for the diagnosis of oral pathologies.

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Conflicts of interest

The author(s) declare(s) that they have no conflicts of interest.

Data availability statement

The data supporting the findings of this systematic review were extracted from publicly available studies accessed through the Medline® (PubMed) and Embase® (Elsevier) databases, as described in the methodology. No new datasets were generated or analyzed specifically for this review.

Author contribution statement

Dr. Olfa Zaghden: Data collection, conceptualization, methodology, and writing the original draft. Dr. Timothé Debré: Data collection, conceptualization and editing. Dr. Thien Huong Nguyen: Review and validation. Dr. Lucas Duong: Review and Validation. Dr. François Ferré: Supervision, Review and validation.

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