RSBO

ISSN:
Electronic version: 1984-5685
RSBO. 2024 Jul-Dec;21(2):405-21

Literature Review Article

Magnetic resonance imaging signal intensity in the characterization of odontogenic lesions: a systematic review

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Received for publication: January 25, 2024. Accepted for publication: March 19, 2024.

Keywords:
magnetic resonance imaging; neoplasm; odontogenic tumors; odontogenic cysts; dental tissue neoplasms.

Abstract

Introduction: Odontogenic lesions content can be differed using magnetic resonance imaging (MRI) signal intensity (SI). **Objective:** This systematic literature review addresses the use of MRI SI for the characterization and differentiation of maxillomandibular odontogenic lesions. **Material and methods:** Databases were searched for original research studies up to August 2023. The following keywords were used: "magnetic resonance imaging" combined with "maxillofacial pathology," "oral pathology," "odontogenic tumors," "dental tissue neoplasms," and "odontogenic cysts," as well as the histologic denomination of benign odontogenic lesions according to the World Health Organization classification. No language restrictions were applied. **Results:** Sixteen investigations were identified regarding distinct odontogenic lesions such as ameloblastoma, odontogenic

keratocysts (OKCs), and dentigerous cysts. Researchers used various terminologies to describe SI, which influenced the findings of the review. **Conclusion:** MRI SI can be useful in the differentiation of multicystic ameloblastomas from other odontogenic lesions; notably, multicystic ameloblastomas exhibit heterogeneous SI in T2-weighted images, such that cystic components exhibit higher SI compared with solid content. Dentigerous cysts exhibit high SI in T2-weighted images, while OKCs eventually exhibit lower SI. The terminology used for description of SI is heterogeneous and requires standardization to improve communication among researchers and clinicians. PROSPERO registration number CRD42021276536.

Introduction

Odontogenic lesions originate from tooth-producing tissues or their remnants, in conjunction with maxillofacial structures [22]. They represent a wide range of histopathological types and demonstrate various degrees of differentiation and aggressiveness [22]. These lesions are frequently detected initially by panoramic radiographs or cone-beam computed tomography examinations.

Panoramic radiographs and cone-beam computed tomography have limitations inherent to the technique, such as superimposed structures and inadequacy for accurate observation of soft tissues, respectively. Cone-beam computed tomography is widely used in surgical planning for odontogenic lesions, where it provides three-dimensional views of lesions and adjacent anatomic structures, as well as comprehensive assessments of bone tissue [1]; magnetic resonance imaging (MRI) is also increasingly applied for the assessment of odontogenic lesions because MRI can provide fundamental information for differential diagnosis [23].

Thus, the assessment of odontogenic lesions contents and margin features by MRI have been extensively explored by researchers, particularly concerning lesion characterization according to signal intensity (SI) in T1-weighted, T2-weighted, and short TI (or Tau) inversion recovery (STIR) images. However, because the lesions features previously published exhibit considerable heterogeneity, with diverse histological types and classifications, their SI findings are not presumed to exhibit common patterns. Additionally, SI is often regarded as a qualitative assessment; it is typically described using various terms, such as "high SI" [3-5, 10, 11, 15, 20, 25, 28] as a synonym for "hyperintense" [12, 13, 25, 31, 32], "low SI" [5, 9, 10, 20, 25] as a synonym for "hypointense" [12, 21, 31-33], or both terms concurrently [33].

The objective of this systematic review was to summarize the SI features of odontogenic lesions and to discuss the terminology used in published descriptions of those lesions. The following questions were considered: The following questions were addressed: 1) "What is the SI of odontogenic lesions according to MRI assessment?"; 2) "What is the terminology applied by the investigators to describe lesions SI?".

Material and methods

Protocol and registration

This systematic review was registered at the National Institute for Health Research, International Prospective Register of Systematic Reviews (PROSPERO), with the registration number CRD42021276536. The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) checklist was followed when writing this manuscript [14].

Data selection

The selection of studies potentially eligible for inclusion in this systematic review was performed using PubMed (United States National Institutes of Health's National Library of Medicine), Embase (Excerpta Medica Database), Scopus (Elsevier), and Web of Science (Institute of Scientific Information – Clarivate Analytics) databases. These databases were searched without language restrictions; articles published on or before September 10, 2021 were included. Keywords were selected considering Medical Subject Headings at the time of the search. Search strategies were established for each database based on the following search keywords: "odontogenic tumors" AND "magnetic resonance imaging"; "dental tissue neoplasms" AND "magnetic resonance imaging"; "maxillofacial pathology" AND

"magnetic resonance imaging"; "oral pathology" AND "magnetic resonance imaging"; "ameloblastoma" AND "magnetic resonance imaging"; "squamous odontogenic tumor" AND "magnetic resonance imaging"; "calcifying epithelial odontogenic tumor" AND "magnetic resonance imaging"; "adenomatoid odontogenic tumor" AND "magnetic resonance imaging"; "ameloblastic fibroma" AND "magnetic resonance imaging"; "primordial odontogenic tumor" AND "magnetic resonance imaging"; "odontoma" AND "magnetic resonance imaging"; "dentinogenic ghost cell tumor" AND "magnetic resonance imaging"; "odontogenic fibroma" AND "magnetic resonance imaging"; "odontogenic myxoma" AND "magnetic resonance imaging"; "cementoblastoma" AND "magnetic resonance imaging"; "cements-ossifying fibroma" AND "magnetic resonance imaging"; "odontogenic keratocystic tumor" AND "magnetic resonance imaging"; "odontogenic keratocyst" AND "magnetic resonance imaging"; "radicular cyst" AND "magnetic resonance imaging"; "inflammatory collateral cyst" AND "magnetic resonance imaging"; "dentigerous cyst" AND "magnetic resonance imaging"; "lateral periodontal cyst" AND "magnetic resonance imaging"; "botryoid odontogenic cyst" AND "magnetic resonance imaging"; "glandular odontogenic cyst" AND "magnetic resonance imaging"; "calcifying odontogenic cyst" AND "magnetic resonance imaging"; "orthokeratinized odontogenic cyst" AND "magnetic resonance imaging"; "gingival cysts" AND "magnetic resonance imaging". Because odontogenic keratocysts were previously regarded as "keratocyst odontogenic tumors," the keyword "keratocyst odontogenic tumor" was also used in the search.

Eligibility criteria

Types of studies

Original research studies were considered eligible for inclusion. Abstracts, case reports, oral presentations, and literature reviews were excluded. Research investigations were also excluded if they only used dynamic contrast enhanced MRI (DCE-MRI), contrast-enhanced images (CE), diffusion-weighted magnetic resonance imaging (DWI), and/or apparent diffusion coefficient (ADC).

Types of lesions

Observational studies involving odontogenic maxillofacial lesions, which used MRI and provided descriptions of SI, were included in the data selection.

Data extraction

Data extraction and selection were performed using "Rayyan QRI" [26]. Two reviewers with (Oral radiologists with MRI training) initially screened the titles and abstracts; they then evaluated the full text of each study to choose eligible publications. Disagreements between the reviewers were resolved by discussion; when an agreement could not be reached, other collaborators were consulted. The following data were extracted and summarized: author information, including the author's location (country), and the year of study publication; histological type and number of lesions evaluated; investigation objective; lesion SI in MRI; and study main results and conclusions. The data search keywords and results from the databases consulted in this study are summarized in a flow chart (figure 1) [27]. The main literature findings are shown in tables I and II.

Data analysis–risk of bias

The risk of bias among selected studies was evaluated using the Joanna Briggs Institute risk of bias assessment tool for observational studies [21]; the results are shown in table III.

Results

In total, 1291 studies were initially identified in the database search using all keywords. After the application of inclusion and exclusion criteria, as well as the removal of duplicate articles, 1275 studies were excluded. Finally, 16 studies [2, 3, 5, 9-13, 16, 20, 28, 31-33] were included in the review. A flow diagram (version 2020) for study selection is shown in figure 1 [27]. A summary of the selected studies is provided in table I, along with each study's main objective, results, and conclusions.

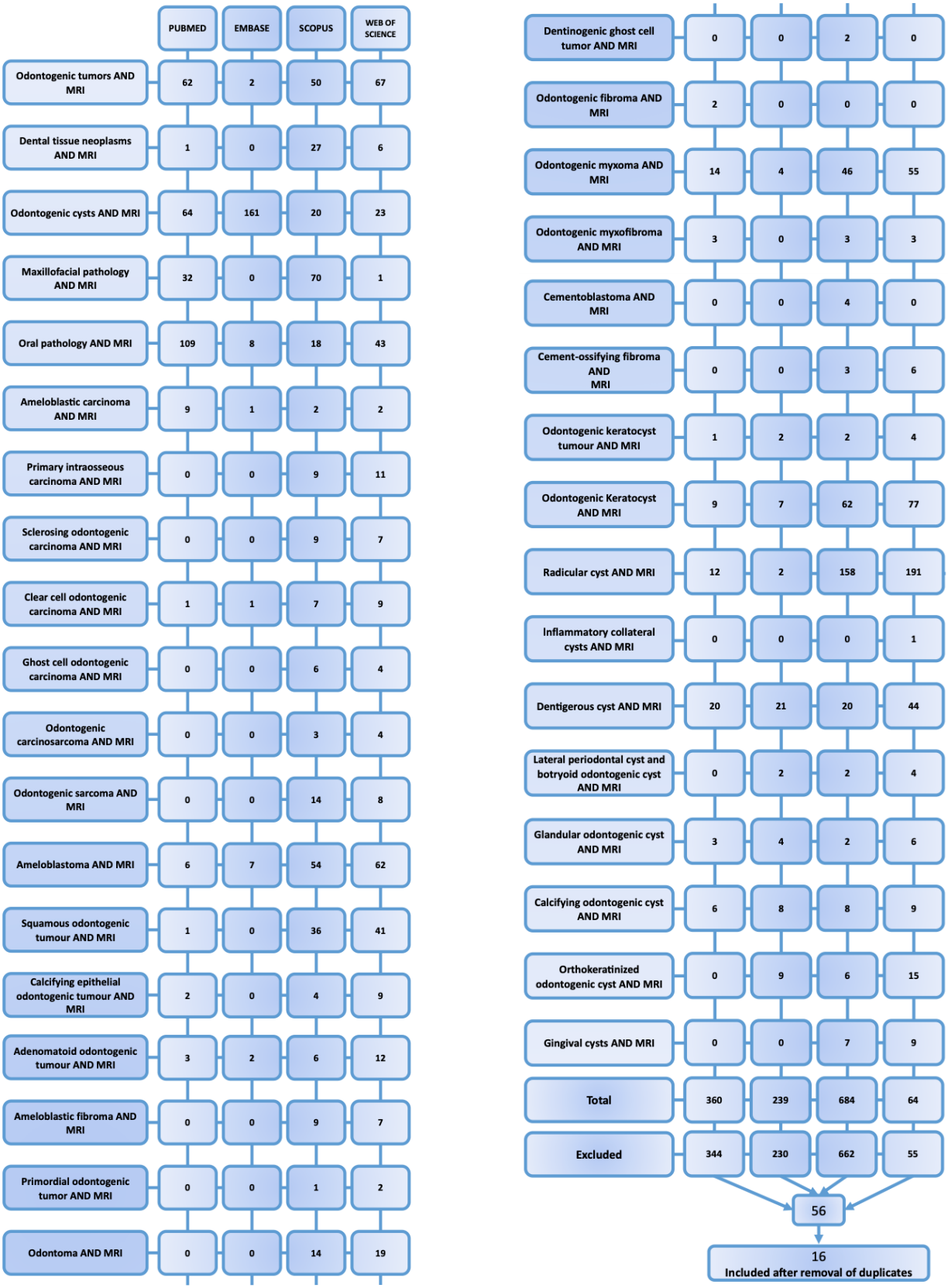

Figure 1 – Flow chart with the literature search

Table I – Summary of studies included in this review. Authors and year of publication, country of investigation origin, magnetic resonance imaging (MRI) equipment and potency (in Teslas – T); number of lesions assessed in the study (n); odontogenic lesions assessed according to histological classification; main objective results and conclusions of the selected study

Authors Year	Country MRI Teslas	n	Odontogenic lesions assessed	Objective	Main results and conclusions
Minani *et al.* [20]	Japan 0.064T Toshiba, USA	46	Multicystic ameloblastoma OKC Other cysts: (radicular cyst, dentigerous cyst, simple bone cyst, dermoid cyst)	Differentiation of ameloblastomas, OKCs and other mandibular cysts using CT and MRI	Shell-like bulgings of the bone cortex were more effectively demonstrated with conventional radiography and/or CT in six cases, and soft-tissue invasion was overestimated with MR imaging in four cases
Hisatomi *et al.* [10]	Japan 1.5T Magnetom Vision; Siemens, Germany	27	OKC Dentigerous cyst Odontogenic glandular cyst Nasopalatine duct cyst	Assessment of odontogenic epithelial lesions imaging features in MRI using SI and Gd-T1WI	MRI features corresponded to histopathological findings. However, for the I glandular odontogenic cyst it was not possible to demonstrate the cystic characteristics MRI
Asaumi *et al.* [3]	Japan 1.5T Magnetom vision; Siemens, Germany	10	Multicystic ameloblastoma	MR features and DCE-MRI of ameloblastomas	For the solid content, ameloblastomas presented a predilection for intermediate SI on T1WI, high signal intensity on T2WI, and enhancement in DCE images. For the cystic portion, demonstrated a homogeneous intermediate SI on T1WI and homogeneous high signal intensity on T2WI, with no enhancement
Konouchi *et al.* [15]	Japan 1.5T Magnetom vision; Siemens, Germany	13	Unicystic, plexiform and follicular ameloblastoma OKC Dentigerous cyst	Evaluation of the use of CET1WI in the diagnosis of unilocular radioluscencies	The images of unilocular radiolucent lesions were differentiated from unicystic ameloblastoma based on the imaging features provided by MRI and CE images. Thick enhancement of the wall of the lesions and the presence of small intraluminal nodules (i.e., characteristic features of unicystic ameloblastoma) were detected only by CE images
Hisatomi *et al.* [11]	Japan 1.5T Magnetom vision; Siemens, Germany	12	Unicystic and multicystic ameloblastoma	Assessment of CE-MRI and DCE_MRI of unilocular cystic-type ameloblastomas suspected of being cystic lesions due to homogeneously bright high signal intensity on T2WI	CE-T1WI and DCE-MRI were useful in the differential diagnosis of unilocular cystic-type ameloblastomas with homogeneously bright high signal intensity on T2WI or STIR

Continued...

Continuation of table I

Authors Year	Country MRI Teslas	n	Odontogenic lesions assessed	Objective	Main results and conclusions
Srinivasan *et al.* [31]	India 1.5T Avanto; Siemens, Germany	20	Odontogenic Myxoma OKC Dentigerous cyst Multicystic and unicystic ameloblastoma	To evaluate the use of DWI and ADC in the differentiation of odontogenic cysts and tumours	Cystic areas of ameloblastoma showed free diffusion, whereas the solid areas showed restricted diffusion; OKC showed restricted diffusion. There was a significant difference between the ADC values of OKC and cystic ameloblastoma
Kheir *et al.* [13]	South Africa T NR	10	Odontogenic Myxoma	Describe imaging features of odontogenic myxomas using distinct imaging modalities	The use of combined of imaging modalities can accurately reveal the true margins and extent of tumors, which is useful in differentiating odontogenic myxoma from other tumors with similar presentation
Apajalahti *et al.* [2]	Finland 1.5T Magnetom vision; Siemens, Germany	5	Ameloblastoma	Imaging features assessment	Contrast-enhanced CT and MRI aid in distinguishing between ameloblastomas and other cystlike lesions because they allow for visualization of the mixed cystic and solid content of nonunicystic ameloblastomas
Probst *et al.* [28]	Germany 1.0T; 1,5T and 3T Magnetom Harmony and Vision (Siemens, Germany); Achieva 3.0T; (Philips medical systems, Germany)	20	OKC	Differentiation between OKC and other odontogenic cystic lesions using MRI	Odontogenic cysts appeared with homogeneously high SI of cystic walls at contrast-enhanced MRI, while OKCs showed homogeneously or heterogeneously low SI after contrast enhancement
Han *et al.* [9]	China 1.5T Signa TwinSpeed system (GE Healthcare, USA)	40	Multicystic and unicystic ameloblastomas OKC Dentigerous cyst	Caracterization of ameloblastomas and OKCs using DWI	DWI and ADC can be used as an adjuvant tool to differentiate OKC and unicystic ameloblastomas, although the ADC values of dentigerous cysts overlap with those of OKCs
Juerchott *et al.* [12]	Germany NR	11	Radicular cyst	Differentiation between RC and granuloma using MRI in cases pre-apicectomy	MRI SI allowed for a differentiation between cysts and granulomas, as well as CE images

Continued...

Continuation of table I

Authors Year	Country MRI Teslas	n	Odontogenic lesions assessed	Objective	Main results and conclusions
Lizio *et al.* [16]	Italy 1.5T Signa HDxt; GE Medical System, USA	34	Radicular cyst	Effectiveness of MRI in the Differentiation of periapical lesions of endodontic origin	A strong inter-rater reliability was observed between the two radiologists and the two pathologists. The reliability and accuracy of MRI were high, highlighting the usefulness of MRI as a diagnostic method for periapical endodontic lesions
Ogura *et al.* [25]	Japan 1.5T Exelart Vantage, MRT; (Canon Medical Systems, Japan)	16	OKC Dentigerous cyst Nasopalatine duct cyst Radicular cyst	Characterization of jaw lesions using DWI	Mean ADC of OKC was lower than DC, nasopalatine duct cyst and simple bone cyst. ADC can be used to differentiate cystic lesions of the jaws
Baba *et al.* [5]	Japan 1.5T and 3T Philips and Siemens	6	Desmoplastic ameloblastoma	Imaging features in MRI and CT	All lesions showed well-defined borders. MRI should also be consulted, particularly for honeycomb-like lesions with well-defined margins, bone expansion and anterior location on radiographs or CT. Findings by MRI such as solid low-signal-intensity, hyperintense cystic foci and persistent enhancement pattern will suggest the diagnosis of desmoplastic ameloblastoma
Vanagundi *et al.* [32]	India 3T Magnetom Skyra (Siemens, Germany)	27	OKC Unicystic ameloblatoma Dentigerous cyst	To compare the ADC values derived from DWI with the T1 and T2 signal intensities for lesions differentiation	SI did not significantly differ considering the three lesions. Functional DWI can be of great benefit in further characterization of these jaw lesions
Wamasing *et al.* [33]	Japan 3T Magnetom Spectra 3T scanner (Siemens, Germany)	127	OKC Dentigerous cyst Unicystic ameloblastoma	To compare ADCs between ameloblastoma, OKC and dentigerous cyst	All dentigerous cysts and 36% of OKCs had contact with an impacted tooth; ADC values were significantly different between dentigerous cysts as well as unicystic ameloblastomas and between OKCs and unicystic ameloblastomas. However, they were not significantly different between dentigerous cysts and OKCs

Abbreviations: CT: computed tomography; OKC: odontogenic keratocyst; CE: contrast-enhanced images; DWI: diffusion-weighted magnetic resonance imaging; ADC: apparent diffusion coefficient; SI: signal intensity; T1WI: T1-weighted imaging; T2WI: T2-weighted imaging; NR: not reported; Gd-T1WI: T1-weighted images obtained using intravenous injection of Gd-DTPA; DCE: dynamic contrast-enhanced images; MRI: magnetic resonance imaging

The oldest study included was from 1996 [20] and the most recent study was from 2021 [33]. The MRI equipment strength ranged from 0.064T [20] to 3T [5, 32, 33]. Researchers also considered the use of other MRI techniques, such as T1-weighted images with intravenous contrast injection [10], DCE images [11], and DWI [9, 25, 31-33].

The numbers of lesions analyzed ranged from five [2] to 127 [33]. The histological types of lesions assessed were (in order of frequency): ameloblastomas [2, 3, 5, 9, 11, 15, 20, 31-33], OKCs [9, 10, 15, 20, 28, 31-33], dentigerous cysts [9, 10, 15, 20, 25, 31-33], radicular cysts [12, 16, 25], nasopalatine duct cysts [10, 25], odontogenic myxomas [13, 31], and odontogenic glandular cysts [10]. Solid and cystic contents of multicystic ameloblastomas were separately evaluated in some investigations [3, 9, 11, 20, 31], while other investigations evaluated such lesions as single entities [2, 5, 15].

The terminology used to describe SI differed among studies, as indicated in tables I-III. To describe SI uniformity (visual pattern homogeneity), the terms "homogeneous" and "heterogeneous" were used by most researchers [2-5, 9-11, 13, 15, 16, 20, 25, 28, 32, 33]. The term "inhomogeneous" [12] was sometimes used to describe a mixed pattern lesion; this term was not used in many studies [9, 20, 31-33]. Concerning SI itself, the following terms were used: "high SI" [3-5, 9, 10, 15, 20, 25, 32] or "hyperintense" [12, 13, 31-33], with variations such as "slight high" [3, 4, 10, 11], "bright high" [2, 10], "markedly high" [11, 15], "extremely high" [3, 15, 33]; "intermediate SI" [2-4, 10, 11, 13, 28] or "isointense" [10, 33]; and "low SI" [5, 9, 10, 13, 15, 20, 25] or "hypointense" [12, 31-33], with variations such as "moderately low" [5] and "slight low" [11]. Table II shows the SI terms used by each author. STIR images were described by four authors [11, 16, 25, 28] and the use of T2-weighted imaging with fat suppression was mentioned by five other authors [2, 9, 12, 33]. Figures 2 and 3 show representative SI terms, selected by the authors of the present review, using the most recent terms applied in the literature.

The risk of bias assessment is shown in table III. Confounding factors included the lack of information concerning MRI equipment, use of various types of equipment, and the absence of histopathology confirmation. Two articles did not report the MRI equipment strength [12, 13].

Table II – Lesion signal intensity in T1-weighted images, T2-weighted images, and STIR images, when available in the studies included in this review. Terms used by the authors to describe signal intensity were maintained

Author and year	Studied odontogenic lesion	Uniformity		Signal intensity		
		T1	T2	T1	T2	STIR
Unicystic ameloblastoma						
Konouchi *et al.* [15]	Unicystic ameloblastoma (n=3)	HO	HO	Low SI (hypointense)*	Markedly high SI (Markedly hyperintese)*	NR
Hisatomi *et al.* [10]	Unicystic ameloblastoma (n=3)	HO	HO	Intermediate SI (n=2) Slight high(n=1) (slight hyperintense)*	Bright high SI (Markedly hyperintese)*	NR
Srinivasan *et al.* [31]	Ameloblastoma (unicystic: 2)	NR	NR	Hypointense	Hyperintense	NR
Han *et al.* [9]	Unicystic ameloblastoma (n=11)	NR	NR	Low to high SI (isointense)*	High SI (hyperintese)*	NR
Vanagundi *et al.* [32]	Unicystic ameloblastoma (n=5)	NR	NR	Hypointense	Hyperintense	NR
Wamasing *et al.* [33]	Unicystic ameloblastoma (n=8)	HO (n=6) HE (n=2)		Isointense (n=6) Hypointense (n=2)	Extremely high SI (n=6) (Markedly hyperintense)* High SI (n=2 hyperintese)*	NR

Continued...

Continuation of table II

Author and year	Studied odontogenic lesion	Uniformity		Signal intensity		
		T1	T2	T1	T2	STIR
Solid content of ameloblastoma						
Asaumi *et al.* [3]	Solid content ameloblastoma (n=10)	NR	NR	From intermediate to slight high SI (from intermediate to slight hyperintense)*	From intermediate to high SI (hyperintese)*	NR
Hisatomi *et al.* [10]	Solid ameloblastoma (n=9)	Most HO (n=5) HO (n=4)	Most HO (n=4) HO (n=5)	Intermediate SI (n=5) Most slight high + intermediate SI (n=1) Most intermediate, marginal slight high SI (n=1) (Most isointense and slight hyperintense)* Most slight low, marginal intermediate SI (n=1) Slight high SI (n=1) (Slight hyperintense; slight low)*	Most bright high + intermediate SI (n=3) (Most bight hyperintense and isointense) Most bright high marginal high SI (n=1) Bright high SI (n=5) (Markedly hyperintense)*	Same as described for T2
Srinivasan *et al.* [31]	Ameloblastoma (solid content) (n=8)	NR	NR	Hypointense	Intermediate to high SI (Intermediate to hyperintense)*	NR
Han *et al.* [9]	Multicystic ameloblastoma (n=11)	NR	NR	Low to intermediate SI (hypointense to intermediate)*	High SI (hyperintense)*	NR
Apajalahti *et al.* [2]	Multicystic ameloblastoma (n=5)	HO	HO or HE	Intermediate	High SI (hyperintense)*	NR
Cystic content of ameloblastoma						
Asaumi *et al.* [3]	Cystic content ameloblastoma (n=10)	HO	HO	From low SI to slight high (from hypointnse to slight hyperintese)*	High SI (hyperintese)*	NR
Minani *et al.* [20]	Multicystic ameloblastoma (n = 19)	HE	HE	Low SI (hipointese)*	High SI (hyperintese)*	NR
Srinivasan *et al.* [31]	Ameloblastoma (cystic content (n=8)	NR	NR	Hypointense	Hyperintense	NR
Han *et al.* [9]	Multicystic ameloblastoma (n=11)	NR	NR	Low to high SI (Isointense)*	High SI (n=11) (hyperintese)*	NR

Continued...

Continuation of table II

Author and year	Studied odontogenic lesion	Uniformity		Signal intensity		
		T1	T2	T1	T2	STIR
Apajalahti *et al.* [2]	Multicystic ameloblastoma (n=5)	HO	HO	Intermediate (Isointese)*	Bright SI (hyperintese)*	NR
Desmoplastic ameloblastoma						
Baba *et al.* [5]	Desmoplastic ameloblastoma (n=6)	HE	HE	Intermediate SI; linear low SI (hypointense)* SI were observed in 5 cases	Moderately low SI; with small cystic high SI (Moderately hypointense with hyperintense)* Linear low SI were observed in 5 cases (Linear hypointense)*	NR
OKC						
Hisatomi *et al.* [10]	OKC (n=7)	HO (n=6) HE (n=1)	HE	Most intermediate to high SI (Most isointense to hyperintense)*	Most low to high mixed SI (Most hypointese to hyperintense)*	NR
Konouchi *et al.* [15]	OKC (n=4)	HO	HE	Intermediate-high SI (Isointese to hyperintense)*	High markedly SI (Markedly hyperintense)*	NR
Srinivasan *et al.* [31]	OKC (n=5)	NR	NR	Hypointense	Hyperintense	NR
Probst *et al.* [28]	OKCs (n=10)	Most HE	Not clear	Tended to be of intermediate SI (isointense)*	Most high SI (Most hyperintese)*	Most high SI (Most hyperintese)
Han *et al.* [9]	OKC (n=15)	NR	NR	Low to high SI (Hypointense to hyperintense)*	High SI (Hyperintense)	NR
Ogura *et al.* [25]	OKC (n=5)	HO	Low SI	High SI (Hyperintense)*	High SI (Hyperintense)*	NR
Vanagundi *et al.* [32]	OKC (n=17)	NR	HE	Hypointense (52.9%) Hyperintense (47.1%)	Hypointense (23.5%) Hyperintense (76.5%)	NR
Wamasing *et al.* [33]	OKC (n=39)	HE (n=37) HO (n=2)		Hypointense (n=3) Isointense (n=29) Hyperinense (n=7)	Low SI (n=6) (Hipointense)* High SI (n=30) (Hyperintense)* Extremely high SI (n=3) (Markedly Hyperintense)*	NR
Dentigerous cyst						
Hisatomi *et al.* [10]	Dentigerous cyst (n=3)	HO	HO	Slight high SI (Slight Hyperintense)*	High SI (Hyperintense)*	NR

Continued...

Continuation of table II

Author and year	Studied odontogenic lesion	Uniformity		Signal intensity		
		T1	T2	T1	T2	STIR
Konouchi *et al.* [15]	Dentigerous cyst (n=3)	HO	HO	Low SI (Hypointense)	Markedly high SI (Markedly Hyperintense)*	NR
Srinivasan *et al.* [31]	Dentigerous cyst (n=2)	NR	NR	Hypointense	Hyperintense	NR
Han *et al.* [9]	Dentigerous cyst (n=3)	NR	NR	low to high SI (Hypointense to hyperintense)*	High SI (n=3) (Hyperintense)*	NR
Ogura *et al.* [25]	Dentigerous cyst (n=4)	HO (n=2)	HE (n=2)	High SI (Hyperintense)*	High SI (Hyperintense)*	High SI
Vanagundi *et al.* [32]	Dentigerous cyst (n=5)	NR	NR	Hypointense (40%) Isointense to hyperintense (60%)	Hyperintense	NR
Wamasing *et al.* [33]	Dentigerous cyst (n=80)	HE (n=70) HO (n=3)		Hyperintense (n=58) Hypointense (n=1) Isointense (n=21)	High SI (n=63) (Hyperintense)* Extremely high SI (n=17) (Markedly hyperintense)*	NR
Glandular odontogenic cyst						
Hisatomi *et al.* [11]	Glandular odontogenic cyst (n=1)	HO	HO	Intermediate SI	High SI (Hyperintense)*	NR
Nasopalatine dusct cyst						
Hisatomi *et al.* [11]	Nasopalatine dusct cyst (n=4)	HO	HO	High SI (Hyperintense)*	High SI (Hyperintense)*	NR
Ogura *et al.* [25]	Nasopalatine duct cyst (n=3)	HE	Low SI (n=1) High SI (n=2)	High SI (Hyperintense)*	High SI (Hyperintense)*	NR
Adenomatoid odontogenic tumor						
Asaumi *et al.* [3]	Adenomatoid odontogenic tumor (n = 3)	HO	HO	Case 1, 2 and 3: Low SI (Hypointense)	Case 1: Slight high (Slight Hyperintense)* Case 3: high in cystic portion and intermediate to high in the solid portion (Hyperintense and Isointense)*	NR
Odontogenic myxoma						
Srinivasan *et al.* [31]	Myxoma (n=3)	NR	NR	Hypointense	Hyperintense	NR

Continued...

Continuation of table II

Author and year	Studied odontogenic lesion	Uniformity		Signal intensity		
		T1	T2	T1	T2	STIR
Kheir *et al.* [13]	Odontogenic myxoma (n=33)	HE	HE 90%	Low to intermediate SI (hypointense to isointense)	Hyperintense masses	NR
Radicular/Periapical cyst						
Ogura *et al.* [25]	Radicular cyst (n=3)	HO		Low SI (Hypointense)	High SI (Hyperintense)*	High SI
Lizio *et al.* [16]	Periapical cyst (number of the lesions not specified)	NR	NR	Low SI (Hypointense)	Internal content: high SI (Hyperintense)* Fibrous wall of the cyst was evident and hypointense	NR
Juerchott *et al.* [12]	Radicular cyst (5)	HO	HO	Authors classified the lesions center as "hyperintense" or "hypointense" but not clearly mentioned which lesion has each SI. Also, used the term "inhomogeneous" that was translated to HE in this table		NR
Konouchi *et al.* [15]	Ameloblastoma follicular (n=1) Ameloblastoma plexiform (n= 3)	HO	HE	Low SI (hypointense)*	High SI, with multifocal markedly high corresponding to cystic portions (Hyperintense and Markedly hyperintense)*	NR

Abbreviations: HE: heterogeneous; HO: homogeneous; SI: signal intensity; NR: not reported; OKC: odontogenic keratocyst

* Terms used by the authors to describe SI

Table III – Risk of bias among the included studies, according to the Joanna Briggs Institute assessment tool [22]

Author	Were the criteria for inclusion in the sample clearly defined?	Were the study subjects and the setting described in detail?	Was the exposure measured in a valid and reliable way?	Were objective, standard criteria used for measurement of the condition?	Were confounding factors identified?	Were strategies to deal with confounding factors stated?	Were the outcomes measured in a valid and reliable way?	Was appropriate statistical analysis used?
Minani *et al.* [20]	Yes	Yes	Yes	Yes	Yes	NA	Yes	Yes
Hisatomi *et al.* [10]	Yes	Yes	Yes	Yes	Yes	NA	Yes	Yes
Asaumi *et al.* [3]	Yes	Yes	Yes	Yes	Yes	NA	Yes	Yes
Konouchi *et al.* [15]	Yes	Yes	Yes	Yes	Yes	NA	Yes	Yes
Hisatomi *et al.* [11]	Yes	Yes	Yes	Yes	Yes	NA	Yes	Yes

Continued...

Continuation of table III

Author	Were the criteria for inclusion in the sample clearly defined?	Were the study subjects and the setting described in detail?	Was the exposure measured in a valid and reliable way?	Were objective, standard criteria used for measurement of the condition?	Were confounding factors identified?	Were strategies to deal with confounding factors stated?	Were the outcomes measured in a valid and reliable way?	Was appropriate statistical analysis used?
Srinivasan *et al.* [31]	Yes	Yes	Yes	Yes	Yes	NA	Yes	Yes
Kheir *et al.* [13]	Yes	Yes	Yes	Yes	No	NA	Yes	Yes
Apajalahti*et al.* [2]	Yes	Yes	Yes	Yes	Yes	NA	Yes	Yes
Probst *et al.* [28]	Yes	Yes	Yes	Yes	No	NA	Yes	Yes
Han *et al.* [9]	Yes	Yes	Yes	Yes	Yes	NA	Yes	Yes
Juerchott *et al.* [12]	Yes	Yes	Yes	Yes	No	NA	Yes	Yes
Lizio *et al.* [16]	Yes	No	Yes	Yes	Yes	NA	Yes	Yes
Ogura *et al.* [25]	Yes	Yes	Yes	Yes	Yes	NA	Yes	Yes
Baba *et al.* [5]	Yes	Yes	Yes	Yes	Yes	NA	Yes	Yes
Vanagundi *et al.* [32]	Yes	Yes	Yes	Yes	Yes	NA	Yes	Yes
Wamasing *et al.* [33]	Yes	Yes	Yes	Yes	Yes	NA	Yes	Yes

NA: Not applied

Figures 2 and 3 show representative terminology according to signal intensity.

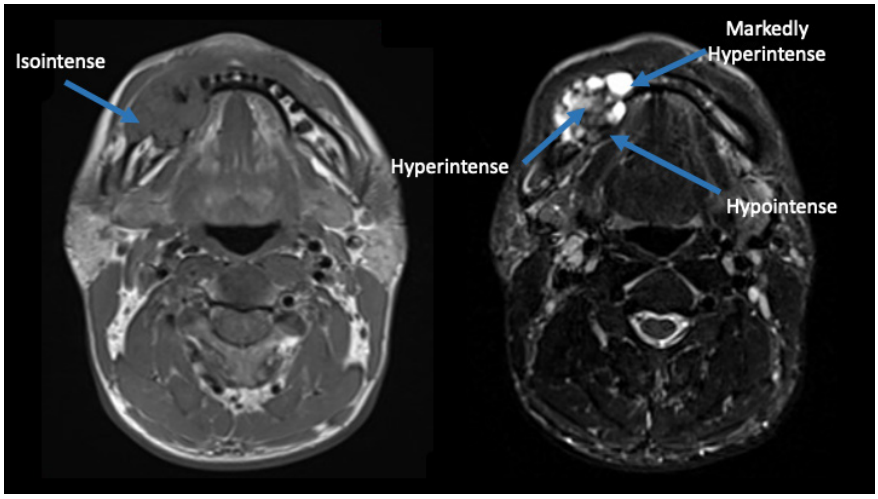

Figure 2 – Representative terms for signal intensity, selected by the authors of the present review, using the most recent terms applied in the literature. Case of multicystic ameloblastoma. From the left to the right: first image is a T1WI image, axial slice, shows an isointense area which has similar intensity compared to muscle. Second image is a STIR image, axial slice, demonstrating hyperintense, hypointense and markedly hyperintense areas

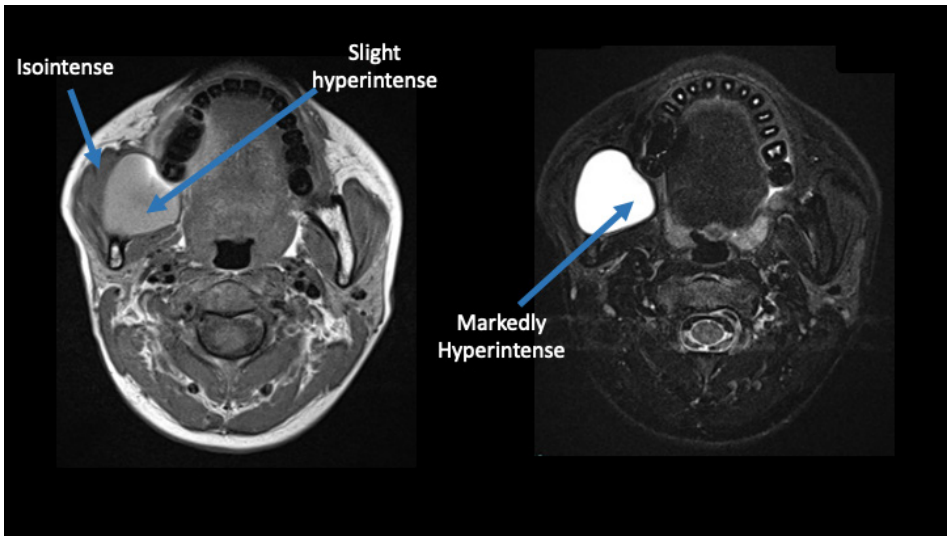

Figure 3 – Representative terms for signal intensity, selected by the authors of the present review, using the most recent terms applied in the literature. Case of unicystic ameloblastoma. From the left to the right: first image is a T1WI image with isointense and slight hyperintense areas. Second image is a STIR image with a markedly hyperintense area

Discussion

MRI is essential for non-invasive diagnosis involving soft tissue; its applications have been widely studied in dentistry [29]. MRI uses a powerful and uniform static magnetic field with radio frequency pulses to create images of target tissues [29]. In particular, T1- and T2-weighted images reflect distinct stages of the pulse sequence [19]; the SI in these images is determined by tissue features, such as the presence of water molecules and adipocytes. T1-weighted images are useful for evaluation of normal and pathological tissues with high fat content or hyperintense SI [30], T2-weighted images are useful for the identification of pathological tissues with high water and fat content or hyperintense SI [18], and STIR imaging is a fluid-sensitive sequence with fat suppression [6].

Considering the differences in SI among T1-weighted images, T2-weighted images, and STIR images, a lesion is likely to exhibit distinct SI in each type of images. Each lesion's histopathological features are also likely to exhibit distinct SI, as demonstrated in the investigations included in this review. Although this argument appears logical, lesions with the same histopathological characteristics and classification varied among patients, as indicated by the heterogeneous findings in table II.

Multicystic ameloblastoma, which comprises 90% of all ameloblastomas diagnosed in the oral cavity [17], frequently exhibited heterogeneous SI in T2-weighted images; SI was also increased in cystic contents within the lesion [2, 5, 15]. For this particular lesion, MRI allows the observation of cystic and solid contents [3], thus enabling differentiation from other purely cystic lesions (e.g., OKCs, unicystic ameloblastomas, and dentigerous cysts). The cystic contents of ameloblastomas often exhibit higher SI in T2-weighted images, compared with T1-weighted images [3, 9, 20, 31], because of its high water content. For example, Apajalahti *et al.* [2] reported that multicystic ameloblastomas had homogeneous SI in MRI.

In our review, all unicystic ameloblastomas and dentigerous cysts exhibited variations of high SI in T2-weighted images [9-11, 15, 25, 31-33]. In contrast, some OKCs exhibited low SI in T2-weighted images [32, 33] and other OKCs exhibited heterogeneous SI in T2-weighted images [10, 15, 32]. The diversity of SI among OKCs is related to the materials contained inside the lesions [7]; for example, the considerable amount of keratin sometimes associated with hyaline [10, 15] is likely to reduce the quantity of water molecules and corresponding SI in T2-weighted images.

The lack of a specific SI pattern prevents differentiation among odontogenic lesions using qualitative SI assessment alone. Hence, complementary MRI techniques (e.g., DWI and DCE images or CE-T1-weighted images) are needed to differentiate among odontogenic lesions. DCE and CE-T1-weighted images are reportedly useful

in the differentiation of odontogenic cysts [10, 11, 15]. DWI can also aid in differentiating unicystic ameloblastomas from OKCs [9] and OKCs from dentigerous cysts [25]; this method does not require the use of contrast [24].

Concerning lesion identification using STIR images, only a few studies have described the use of this MRI parameter [11, 25, 28], although five studies mentioned the use of T2-weighted images with fat suppression [2, 9, 12, 33]. STIR sequence reconstruction produces images that are similar to T2-weighted images; however, because the fat signal is suppressed, non-fatty tissues exhibit higher SI, which may result in higher SI in fluid or fluid-containing areas [6]. This approach facilitates assessment of odontogenic lesions with cystic content because these lesions are highlighted in the resulting images.

Another important consideration is the diverse terminology used to describe the odontogenic lesions. We maintained the SI terms used in each study because we were unable to distinguish some terms, particularly those derived from "high" or "hyperintense" and "low" or "hypointense". For example, "bright high" may be a synonym for "extremely high" or "markedly high", but it is unclear whether "intermediate to high" is a synonym for "slight high". The qualitative classification approach is subjective to observer bias. Hence, a quantitative SI measurement approach could provide allow more accurate detection of slight color variances among images produced using each MRI protocol. Notably, quantitative values were analyzed by Fujita *et al.* [8] using the "SI uniformity" approach; this confirmed that cystic components of ameloblastomas (e.g., unicystic ameloblastomas) could be differentiated from OKCs in both T1-weighted and T2-weighted images.

This review had some limitations. Although the use of SI in the diagnosis of the odontogenic lesions was first published in 1996 [20], we found relatively few studies that fulfilled the inclusion criteria for this review. Furthermore, each study included a small number of lesions. Finally, the heterogeneous SI terminology may have influenced the lesion assessments.

Conclusion

MRI SI can be useful in the differentiation of multicystic ameloblastomas from other odontogenic lesions; notably, multicystic ameloblastomas exhibit heterogeneous SI in T2-weighted images, such that cystic components exhibit higher SI compared with solid content. Dentigerous cysts exhibit high SI in T2-weighted images, while OKCs eventually exhibit lower SI. The terminology used for description of SI is heterogeneous and requires standardization to improve communication among researchers and clinicians.

Acknowledgments

We thank Ryan Chastain-Gross, Ph.D., from Edanz (https://jp.edanz.com/ac) for editing a draft of this manuscript.

Conflict of interest

Authors declare no conflict of interest.

Ethics approval

Not applied.

Funding

No funding was available for this research.

Author's contributions

Luciana Munhoz idea, databases research, manuscript writing, Shunsuke Okada critical review, manuscript drafting; Miki Hisatomi manuscript correction, figures, critical review; Mariko Fujita critical review, idea, manuscript writing; Yudai Shimizu critical review, main concepts, Yoshinobu Yanagi critical review; Emiko Saito Arita critical review, Jun-ich Asaumi critical review and main concepts.

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