Dentomaxillofacial Radiology (2022) 51, 20210450

birpublications.org/dmfr

SYSTEMATIC REVIEW

Artifacts in magnetic resonance imaging caused by dental materials: a systematic review

[1]Lauren Bohner, [1]Marcel Hanisch, [2]Newton Sesma, [3]Moritz Blanck-Lubarsch and [1]Johannes Kleinheinz

[1]Department of Cranio-Maxillofacial Surgery, University Hospital Muenster, Muenster, Germany; [2]Department of Prosthodontics, School of Dentistry, University of São Paulo, São Paulo, Brazil; [3]Department of Orthodontics, University Hospital Muenster, Muenster, Germany

Objectives: The purpose of this systematic review was to search in literature in which severity unintended effects are caused by dental materials in magnetic resonance imaging (MRI), such as to evaluate whether these artifacts hamper the diagnosis in the head and neck region.
Materials and Methods: Clinical studies showing the severity of artifacts which dental materials are capable of causing in MRI of head and neck, such as their influence on diagnostic accuracy, were included in this review. The searches were conducted in four electronic databases (PubMed/Medline, Embase, Scopus and Web of Science), and a manual search was made in the reference lists of papers screened for full-text reading. Risk of bias was assessed using "Quality Assessment Tool for Diagnostic Accuracy Studies-2" (QUADAS-2). The Grading of Recommendations Assessment, Development, and Evaluation (GRADE) was used to assess the quality of evidence.
Results: From 151 studies selected for full-reading, 19 were considered eligible for this review. Artifacts caused by orthodontic appliances were well-documented, and stainless steel brackets were the materials most likely to cause artifacts in MR imaging of head and neck. The literature was scarce for dental implants and restorations. Diagnoses within the oral cavity, but also those of the brain and craniofacial structures, were affected.
Conclusion: Artifacts caused by orthodontic appliances may affect the diagnosis in oral cavity and craniofacial structures. Data regarding dental implants and prosthodontics restorations were inconclusive. The severity of artifacts in MRI and their influence on diagnosis is dependent on dental material features, location in the oral cavity, and magnetic resonance parameters.
Dentomaxillofacial Radiology (2022) **51**, 20210450. doi: 10.1259/dmfr.20210450

Cite this article as: Bohner L, Hanisch M, Sesma N, Blanck-Lubarsch M, Kleinheinz J. Artifacts in magnetic resonance imaging caused by dental materials: a systematic review. *Dentomaxillofac Radiol* (2022) 10.1259/dmfr.20210450.

Keywords: Dental Implants; Magnetic Resonance Imaging; Artifacts

Introduction

Magnetic resonance (MR) is a non-ionizing imaging technique that has been widely used for assessment of anatomical and pathological tissues in the head and neck. Due to the excellent soft tissue contrast provided, MR imaging is indicated for brain imaging, temporomandibular assessment or tumor detection.[1–10] Nonetheless, image quality may be hampered by the presence of artifacts arising either from the system hardware or due to interaction with the human body.[11]

In this regard, dental materials may be capable of causing artifacts in scans of the head and neck region.[12–15] Magnetic susceptibility artifacts may occur due to distortion of static magnetic field homogeneity (B_0) or by gradient distortion due to the induction of eddy currents.[11] This process occurs when the difference between magnetic susceptibility of two structures

Correspondence to: Lauren Bohner, E-mail: lauren.bohner@ukmuenster.de
Received 21 October 2021; revised 07 March 2022; accepted 09 March 2022; published online 31 March 2022

Table 1 Inclusion criteria were determined based on PICOs

PICOs	
Participants	Patients with dental implants, orthodontics appliances, dental or implant-supported prostheses
Intervention or exposition	Magnetic resonance imaging of head and neck
Comparison or control	Patients without dental materials or using plastic appliances
Outcome measure(s)	Assessment of dental-based artifacts
Types of **S**tudies included	Clinical studies

achieve a high rate, resulting in loss of the signal required to form the image. Hence, a black area will appear as result of signal loss, which can hamper the delimitation of anatomical structures. The appearance of artifacts will vary according to the scanned object, its position and size.[11]

Nonetheless, the extent to which the severity of dental material artifacts will hamper the quality of MR is still unclear, since the extension and localization of artifacts are dependent on different aspects. Not only the features of dental materials, but also characteristics of surrounding tissues and MR imaging parameters play an important role in the dimension and distribution of artifacts.[16] Thus, although different imaging protocols are offered to reduce artifacts,[15,17] radiologists are often confronted with uncertainty at the time of diagnosis.

So far, the literature has been controversial, and it has not been possible to provide clinicians with guidelines regarding this issue. In this sense, this systematic review aimed to critically appraise the current evidence in order to answer the following focused questions: What is the severity of unintended effects caused by different dental materials in MR images? Do these artifacts hamper the diagnosis in the head and neck region?

Methods

Protocol registration

This systematic review was conducted according to the PRISMA Guidelines.[18] The registration is available at PROSPERO[19] under the number CRD42021262373.

Eligibility criteria

Clinical studies showing the extent of severity of artifacts that dental materials are capable of causing in MRI of head and neck, such as their influence on diagnostic accuracy, were included in this review (Table 1). Exclusion criteria consisted of 1) any other study design (reviews, letters, conference abstracts, *in vitro*/*ex vivo* studies), or studies written in a language other than English, 2) studies without MRI of head and neck, 3) MRI without the presence of dental materials, 4) studies that did not assess the severity of artifacts regarding location or diagnostic accuracy. No date restriction was applied.

Information sources

All searches were conducted between April and June 2021 and updated in November 2021. Searches were applied in four electronic databases: PubMed/Medline, Embase, Scopus and Web of Science. Additionally, a manual search was made in the reference lists of papers screened for full-text reading.

Search

The main search strategy was constructed based on PICOS (Table 2) and used in the Pubmed/MedLine databases. For further databases, the main search was adapted according to the requirements of each one (Supplementary Material 1).

Studies were selected independently by two reviewers (L.B.; M.H.). First, articles were screened for full-reading based on titles and abstract. The articles screened were

Table 2 Main search strategy

#1	*Magnetic resonance OR MRI OR magnetic resonance imaging*
#2	Artifact OR artifacts OR artefact OR artefacts
#3	Head and neck OR head OR brain OR orofacial OR craniofacial OR intraoral OR craniomaxillofacial
#4	Dental materials OR orthodontic materials OR orthodontic appliances OR orthodontic brackets OR orthodontic wire OR orthodontics OR dental implants OR dental prosthesis OR implant-supported dental prosthesis OR crowns OR metal OR metallic OR titanium OR zirconia OR ceramic
#1 AND #2 AND #3 AND #4	(Magnetic resonance OR MRI OR magnetic resonance imaging) AND (Artifact OR artifacts OR artefact OR artefacts) AND (Head and neck OR head OR brain OR orofacial OR craniofacial OR intraoral OR craniomaxillofacial) AND (Dental materials OR orthodontic materials OR orthodontic appliances OR orthodontic brackets OR orthodontic wire OR orthodontics OR dental implants OR dental prosthesis OR implant-supported dental prosthesis OR crowns OR metal OR metallic OR titanium OR zirconia OR ceramic)

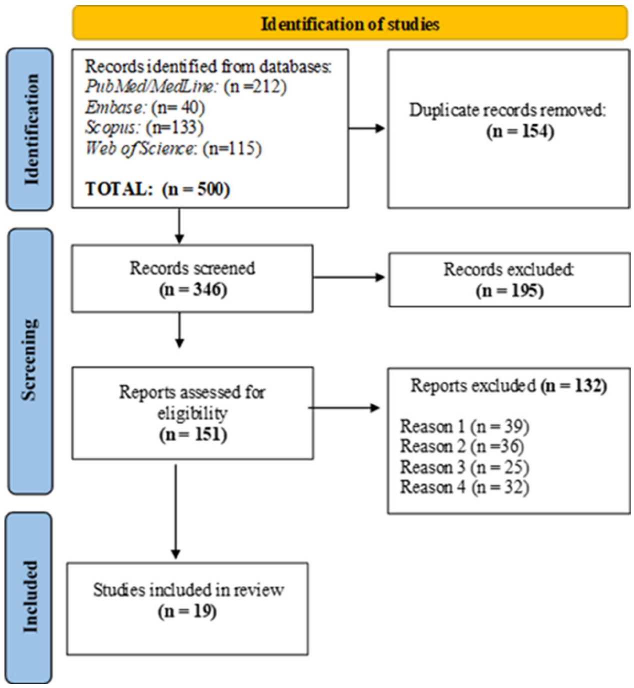

Figure 1 Search strategy.

read in full, and those considered eligible for this review were selected according to the eligibility criteria. Any disagreement on study selection was resolved between the two reviewers. If a consensus was not reached, a third reviewer (J.K.) was consulted.

Data collection process and items
Data were extracted by the first reviewer and results were cross-checked by the second reviewer. The following data were extracted: study data (author, year), sample and material data (sample size, dental material), MRI data (device, MRI sequence, diagnostic purpose) and intervention (evaluation method, evaluation site, reference standard), measurement and results (localization of artifacts, diagnostic accuracy).

Risk of bias in individual studies
Risk of bias was assessed using "Quality Assessment Tool for Diagnostic Accuracy Studies-2" (QUADAS-2).[20] The tool is comprised of four domains, namely, "patient selection", "index test", "reference standard", and "flow and timing". Questions are answered as "Yes", "Unclear", and "No" according to the potential risk of bias (low/unclear/high).

Summary of measures
Presence and localization of artifacts, visualization of anatomical structures, and diagnostic accuracy were considered the main outcomes.

Synthesis of results
Results were described according to the dental material (orthodontic appliances, dental implants, dental restorations). Effects were synthesized based on the presence of artifact (no artifact, moderate artifact, severe artifact) and the diagnosis (diagnosis was possible, diagnosis possible but hampered by artifacts, diagnostic was not possible).

Certainty of evidence
Certainty of evidence was assessed by "The Grading of Recommendation Assessment, Development, and Evaluation" (GRADE).[21]

Results

Study selection
The electronic search resulted in 500 articles, of which 346 articles remained after the removal of duplicates. Of these, 151 publications were chosen for full-reading, and 19 studies were considered eligible for this review (Figure 1). Excluded articles and reason for exclusion are shown on Appendix 2.

Study characteristics
Study characteristics are described in Tables 3 and 4. Fifteen of the included studies evaluated the use of orthodontic appliances, including arch wires, brackets, bands and retainers.[22–35] Dental implants were assessed in six articles,[24,29,32,36–38] and four included dental crowns.[24,29,30,39] One study did not specify the dental materials that were evaluated.[40]

MRI sequences varied according to the imaging purpose (Table 1), and five studies assessed the use of metallic artifact correction.,[3,29,30,34] The purpose of imaging exam tests included assessment of the brain,[23,24,27,28,31] head and neck,[27,34,39] jaw structures[29,30,32] tumor or pathologies,[29,30,38] and temporomandibular disorders.[25,26,33]

The site to be evaluated included craniofacial structures,[34] the oral cavity,[22,26,27,30,31,38] jaw bones and corresponding structures,[22,27,29,30,32,34,39] temporomandibular joint,[22,23,25,33,34] brain,[23,27,29,31,33] orbit,[29] pharynx,[26–28,34,35] cervical structures.[23]

Risk of bias within studies
The QUADAS-2 assessment is shown in Figure 2. The major portion of the studies showed high risk of bias for patient selection, which was possibly related to the study design. The index test was described as having a low risk of bias for all studies. The reference standard was considered of low risk for those studies presenting either a group as control or reference values. A high risk was defined for those studies that did not specify a reference value.

In general, the risk of bias related to applicability concerns was considered low. One study showed high

Table 3 Descriptive characteristics of included studies. ST: slice thickness; FOV: field of view; TR: repetition time; TE: echo time; TSE: turbo-spin-echo; GES: gradient echo sequence; SE: spin-echo; EPI: echo-planar imaging; FSE: fast spin-echo; FLAIR: fluid-attenuated inversion recovery; FS: fat saturated; CISS: constructive interference steady state; TMJ: temporomandibular joint

Author, year	*Study design*	*n*	*MRI device*	*MRI Sequence*	*Coil and position*	*Artifact correction*
Assaf et al., 2014	*in vivo*	12	3T MRI (Siemens Skyra)	1) Non-contrast T1w (TE/TR 3.26/21 ms); 2) non-contrast FS T1w (TR 34 ms); 3) FS T2w TSE with SPACE, TE/TR 113/2000 ms); 4) CISS (TE/TR 3.43/6.85 ms)	20-channel head and neck coil (Siemens medical solutions)	No
Beau et al., 2015	*in vivo*	60	1.5 T MRI System (Siemens Avanto, Siemens AG)	T2 Blade SPAIR transverse, ST 3.5 mm, FOV 240 × 240, TR 4200 ms, TE 131 ms	---	No
Cassetta et al., 2017	*in vivo*	20	3T MRI System	1) Brain evaluation: axial fluid attenuated inversion recovery, TR/TE 9010/114 ms, FOV 240 × 240 mm, ST 5 mm; axial oblique double echo proton density and weighted/ TSE T_2 weighted, TR/TE 5600/114/7 ms, FOV 240 × 240 mm, ST 5 mm. 2) Cervical spine evaluation: sagittal TSE *T*2-weighted, TR/TE 6700/83 ms, FOV 240 × 240 mm, ST 4 mm; sagital TSE T1 TR 400 ms, TE 20 ms, FOV 240 × 240 mm, ST 4 mm; axial T2 GES, TR/TE 816/11 ms, FOV 240 × 240 mm, ST 3 mm; 3) Axial and coronal TSE *T*2-weighted, TR/TE 5600/114/7 ms, FOV 240 × 240 mm, ST 5 mm; 4) TMJ sagittal, axial, coronal proton density and TSE *T*2-weighted, TR/TE 5653/13/102 ms, FOV 160 × 160 mm, ST 2 mm	---	No
Cho et al., 2013	*in vivo*	20	3T MRI System (Sigma 3.0T HDx, GE Healthcare)	1) GES *T*2-weighted: TR/TE 600/17 ms; 2) DWI: spin-echo EPI, TR/TE 8000/75 ms, ST 5.0 mm, FOV 240 mm; 3) PROPELLER DWI: TR/TE 5200/75 ms, ST 5.0 mm, FOV 240 mm.	HD T/R 8ch brain array coil (*In vivo* Corp.)	PROPELLER DWI
Costa et al., 2009	*in vivo*	70	---	1) Sagittal T1 SE ST, TR/TE 430/12 ms, FOV 25 × 25 cm; 2) coronal images, perpendicular to long axis of hippocampus: T1w inversion recovery, TE 14 ms, FOV 16 × 18 cm; 3) axial images parallel to the long axis of the hippocampi: T1w gradient echo, TR/TE 200/5 ms, FOV 22 × 22 cm; fluid attenuated inversion recovery (FLAIR) 4 mm thick,, TR 10099, FOV 21 × 23 cm	---	No
Elison et al., 2008	*in vivo*	10	1.5T MRI System (Siemens Medical Solutions, Sonata)	1) Axial fast-SE T2w, TR/TE = 3500/90 ms; 2) axial and sagittal conventional SE T1w TR/TE = 500/14 ms, ST 5 mm; 3) axial GES, TR/TE = 720/26 ms, ST 4 mm; 4) diffusion-weighted sequence, TR/TE = 6300/137 ms, ST 5 mm	Head coil	No
Gunzinger et al., 2014		25	PET/CT-MRI (GE Healthcare Discovery 750w 3T MRI)	1) In-phase images (dual-echo gradient-echo pulse sequence): TR/TE 4.3/1.3 ms, FOV 50 cm; 2) 2D encoded T1w FSE sequence (axial orientation): TR/TE 339/13.6 ms, ST 3 mm; 3) MAVRIC SL: TR/TE 4.000/7.6 ms; 4) MAVRIC FAST: TR/TE 3.000/7.6 ms	---	MAVRIC
Hinshaw et al., 1988	*in vivo*	4	--	SE:TE/TR 500/30 ms	Head coil (Magnetom, Siemens)	No
Hong et al., 2014	*in vivo*	37	3T MRI System (Intera Achiva, Phillips)	1) T1w, coronal STIR images: TR/TE 3.73 ms/70 ms, FOV 250 mm, ST 3 mm; 2) T1w SE with fat saturation: TR/TE 521/12 ms, FOV 250 mm, ST 3 mm, in sagittal, axial and coronal planes	Eight-element phased array sensitivity-encoding (SENSE) head coil	No
Ladefoged et al., 2015	*in vivo*	148	PET/MR, Siemens Biograph mMR, Siemens Healthcare	Sagittal T1w MPRAGE, *vs* 0.5 × 0.5 x 1mm3	Single-bed position covering head and neck	

(Continued)

Table 3 (Continued)

Author, year	*Study design*	*n*	*MRI device*	*MRI Sequence*	*Coil and position*	*Artifact correction*
Miao et al., 2020	*in vivo*	6	Ingenia 3T, Phillips Healthcare	T2-preprared functional MRI and diffusion prepared DTI : MPRAGE, two dimensional GRE EPI BOLD functional MRI, 3D T2-prepared BOLD functional MRI (TR 2 sec. *vs* 3.75 × 3.75 x 4mm3), two-dimensional SE EPI DTI, 3D diffusion-prepared DTI (*vs* 2.5 × 2.5×2.5 mm3)	--	Optimized higher order shims and distortion correction
Okano et al., 2003	*in vivo*	10	0.5T Flexart, Toshiba	TR/TE 1500/25 ms, FOV 17 × 17 cm, ST 4 mm	Surface coil for TMJ	No
Ozawa et al., 2018	*In vivo*	16	3T (Magnetom Spectra, Siemens)	TR/TE 22.5/2.07 ms, FOV 256 × 256 mm, ST 4 mm	---	No
Probst et al., 2017	*in vivo*	4	3T whole-body MRI scanner, MAGNETOM Verio, Siemens; 1,5T whole-body scanner MAGNETOM Avanto, Siemens	TSE T2: TR 5980 ms, TE 102 ms, ST 2 mm, *vs* 0.86 × 0.86×2 mm3 (coronal), and 0.6 × 0.6×2 mm3 (axial), FOV 260 mm (coronal), 230 mm (axial); TSE SPIR (parasagittal): T2 TR 5980 ms, TE 97 ms, ST 1.5 mm, *vs* 1 × 1×1.5 mm3, FOV 255 mm, T1 TR 750 ms, TE 12 ms, ST 2 mm, *vs* 0.89 × 0.63×2 mm3, FOV 200 mm; TSE (parasagittal) t2: TR 5980 ms, TE 102 ms, ST 2 mm, FOV 200 mm, *vs* 0.89 × 0.63×2 mm3; TSE Warp (VAT,SEMAC): parasagittal T2 TR 8700 ms, TE 90 ms, ST 1.5 mm, *vs* 1 × 1×1.5 mm3, FOV 255 mm	12-channel head coil, patient in supine position	VAT,SEMAC
Sadowsky et al., 1988	*in vivo*	5	--	TMJ: sagittal 5mm T1w head: transverse multiecho sequence, TR/TE 2500/30/100 ms	Standard head coil and specially developed surface coil	No
Sonesson et al., 2021	*in vivo*, *in vitro*	30	1,5T, 3T, Siemens	1) TSE sagittal: TR/TE 592/5–8 ms, FOV 21 × 21, ST 4 mm; 2) TSE coronal: TR/TE 404/5–8 ms, FOV 21 × 21, ST 4 mm; 3) TSE VAT+SEMAC sagittal: TR/TE 592/6 ms, FOV 21 × 21, ST 4.5 mm;4) TSE VAT+SEMAC coronal: TR/TE 404/6 ms, FOV 21 × 21, ST 5 mm	Images acquired in sagittal and coronal orientations	SEMAC, VAT
Wylezinska et al., 2015	*in vivo*	32	1.5T Philips Achieva	Spin echo: TR 450 ms, TE 15 ms, PS 0.88 × 0.88 mm2, ST 2 mm, Bandwidth 259 Hz/px, Orientation axial/sagittal; Gradient echo: TR 30 ms, TE 3.2 ms, PS 1.48 × 1.48 mm2, ST 10 mm, Bandwidth 284 Hz/px, Orientation axial/sagittal; bSSFP TR 2.9 ms, TE 1.5 ms, PS 1.90 × 1.90 mm2, ST 5 mm, Bandwidth 1720 Hz/px, Orientation sagittal/oblique-nasendoscospy; 3D TSE TR 1000 ms, TE 116 ms, PS 0.90 × 0.90 mm2, ST 0.90 mm, Bandwidth 770 Hz/px, Orientation axial	16-channel head and neck radio frequency coil	No
Zachriat et al., 2015	*in vivo*	1	1.5 Tsystem, MAGNETOM Aera, Siemens Healthcare	1) T2w TR/TE 4500/92 ms, SL 5 mm, *vs* 0.96 × 0.72×5 mm; 2) SE echoplanar imaging: TR/TE 4500/113 ms, SL 6 mm, *vs* 1.5 × 1.2×6 mm; 3) T1w GRE: TR/TE 366/4.8 ms, SL 5 mm, *vs* 1.11 × 0.90×5 mm; 4) T2w TSE: TR/TE 3000/84 ms, SL 3 mm, *vs* 1.12 × 0.90×3 mm; 5) T2*w* + WARP: TR/TE 3000/84 ms, SL 3 mm, *vs* 1.12 × 0m90 x3mm	20-channel head coil and 4-channel head coil	WARP
Zhylich et al., 2017	*in vivo*	10	3T (Magnetom Spectra, Siemens)	Sagittal *T*1-weighted (TR/TE 5 1950.0/4.4 msec, ST 1 mm), axial *T*2-weighted (TR/TE 5 4500.0/83.0 msec, ST 3.5 mm); axial gradient recalled (TR/TE 5 620.0/20.0 msec, 3.5 mm thick), axial diffusion-weighted (TR/TE 5 5000.0/93.0 msec, 4 mm thick)	12-channel head coil, patient in supine position	No

Table 4 Study characteristics (continued)

	Diagnostic purpose	*Evaluation site*	*Dental device*	*Material*	*Measurement method*	*Examiners*
Assaf et al., 2014	Oral structures (bone, mandibular and lingual nerve, salivary glands, soft tissue, dental and periodontal structures)	Jaw (jaw angle, upper incisor region, teeth 11,37, nerve at region 36 and 46)	1) Retainers (n = 2); 2) Dental implants (n = 4), 3) Filings or dental crowns (n = 3); 4) Braces (n = 1)	3) Amalgam or gold alloy	Five-point scale (1- Excellent; 5- not visible)	Two oral and maxillofacial surgeons, two radiologists
Beau et al., 2015	---	Maxillary sinus, oral cavity, temporomandibular joints, posterior cerebral fossa	Brackets, retainers	Metal wire, titanium, ceramic or stainless steel	Image interpretability (interpretable, non-interpretable)	Two radiologists
Cassetta et al., 2017	Brain evaluation	Brain, paranasal sinuses, head and neck, cervical region, cervical vertebrae, temporomandibular joint	Brackets, brackets and archwires	Stainless (brackets and archwires), NiTi (archwire)	Artifacts detection (1. No distortion - 5. Complete obliteration)	Two radiologists
Cho et al., 2013	Brain imaging	Bilateral temporal lobes, pons, and orbit	Dental implants	---	Presence of artifacts based on distortion of anatomical structures (Yes/No)	One specialist, two radiologists
Costa et al., 2009	Brain	Brain	Crowns, dental implants, orthodontic appliances (bands, brackets, archwire)	Gold (crowns), titanium (dental implants), metal (orthodontic appliances)	Image interpretability (interpretable, non-interpretable)	One investigator with experience in MRI
Elison et al., 2008	Head	Base of the tongue, body of the mandible, hard palate, orbit/ globes, nasopharynx, pituitary gland, frontal lobem temporal lobe, brain stem	Orthodontic brackets	Titanium, non-metallic, stainless steel	Distortion classification	Three neuroradiologists
Gunzinger et al., 2014	Oropharyngeal cancer	Oral cavity	Dental implants	---	Visualization of anatomical structures (1. good depiction of anatomical structures - 5. oral cavity not assessable), and artifacts (1. no artifacts - 5. severe artifacts)	Two radiologists
Hinshaw et al., 1988	Jaw	--	Dental restorations, linkplus pin and orthodontic bands, zincophosphat cement, parapost and TMS pin, microfilled resin	Gold, amalgam, glands methacrylate, nonprecious metall alloy	Scale (1 no artifacts; 4- severe artifacts)	--
Hong et al., 2014	Tumor detection in oral cavity	Intrinsic tongue muscle, extrinsic muscle, mandible, sublingual gland, submandibular gland, retromolar trigone, floor of mouth, and base of the tongue	Not specified	Metal (not specified)	Detection of primary tumors in comparison with pathology measurements	Two radiologists, two nuclear medicine physicians
Ladefoged et al., 2015	Tumor at head and neck	Tongue, lower tongue, masticatory muscles,	Dental implants	Metal (not specified)	Measurement of artifact size, relative and mean difference (mean and maxi) of SUV	--

(Continued)

Table 4 (Continued)

	Diagnostic purpose	*Evaluation site*	*Dental device*	*Material*	*Measurement method*	*Examiners*
Miao et al., 2020	Brain	Brain	Orthodontic braces	Metal (not specified)	Geometric distortion, comparison between method and with and without braces, quantitative analysis: temporal signal-to-noise ratio, percentage signal change, contrast-to-noise ratio	--
Okano et al., 2003	TMJ dysfunction	TMJ	Brackets, band	Ceramic, metal	Comparison between images with and without orthodontic appliances	Three dental physicians
Ozawa et al., 2018	Speech (MRT movie)	Oral cavity, Velopharynx	Orthodontic appliances	Retainer, brackets	Image distortion (Yes/No)	Single examiner
Probst et al., 2017	Examination of inferior alveolar nerve	Maxilla, mandible, inferior alveolar nerve	Orthodontic retainers, dental implant	Metal (not specified)	Descriptive	--
Sadowsky et al., 1988	TMJ dysfunction	TMJ and brain	Orthodontic appliances	Metal (not specified)	Visual	--
Sonesson et al., 2021	Head assessment	Maxilla, mandible, nasopharynx, tongue, TMJ, cranial base, eye globes	1)Brackets, 2) banded rapid maxillary expansion appliance, 3) retainer, 4) casted Herbst appliance	1)nickel-free, conventional stainless-steel, titanium	4-point scale (0 no artifact; 3- major artefact)	Single examiner
Wylezinska et al., 2015	Speech (MRT movie)	Velum/velopharyngeal wall	Orthodontic arch wires, orthodontic expansion push coils, molar bands, orthodontic brackets	ceramic, ceramic with metallic, stainless steel brackets	Presence and size of artifacts, image distortion and signal intensity change	--
Zachriat et al., 2015	Brain	Frontal, parietal, occiptal and temporal lobes; thalamus; pallidum; pituitary gland, mesenchephalom; cerebellum; pons; medulla oblongata; medulla spinals; lingua; orbita; nasal cavity; frontal, maxillary, sphenoid, and ethmoid sinus; TMJ; atlas; axis; vertebra; nasopharynx; oropharynx; laryngopharynx	Multibrackets	xx	Artifacts level was measured in a five point scale	One radiologist
Zhylich et al., 2017	Head	Base of the tongue, hard palate, body of the mandible, nasopharynx, globes of the eyes, pituitary gland, frontal lobe, temporal lobe and brain stem	Brackets, retainer	Stainless steel (silver), ceramic bracket, mandibular retainer	Artifacts detection (1. No distortion - 5. Complete obliteration)	Two neuroradiologists

concern related to the reference standard, because it deviated from the research question.[31] In addition, an unclear risk was shown for studies that did not describe a reference standard.[24,27,29]

Synthesis of results

Regarding stainless steel brackets, four studies stated that the most severe artifacts were found in oral cavity.[22,23,27,30] Diagnosis of pathological conditions in oral cavity,[22,23,26–28,33–35] maxillary sinus,[22,23] and orbit regions[27,28] was hampered by these appliances. Concerning imaging of brain and temporomandibular joint, results were controversial. Whereas four studies associated severe artifacts to poor brain diagnosis,[22,24,28,31] six studies described it as moderate or

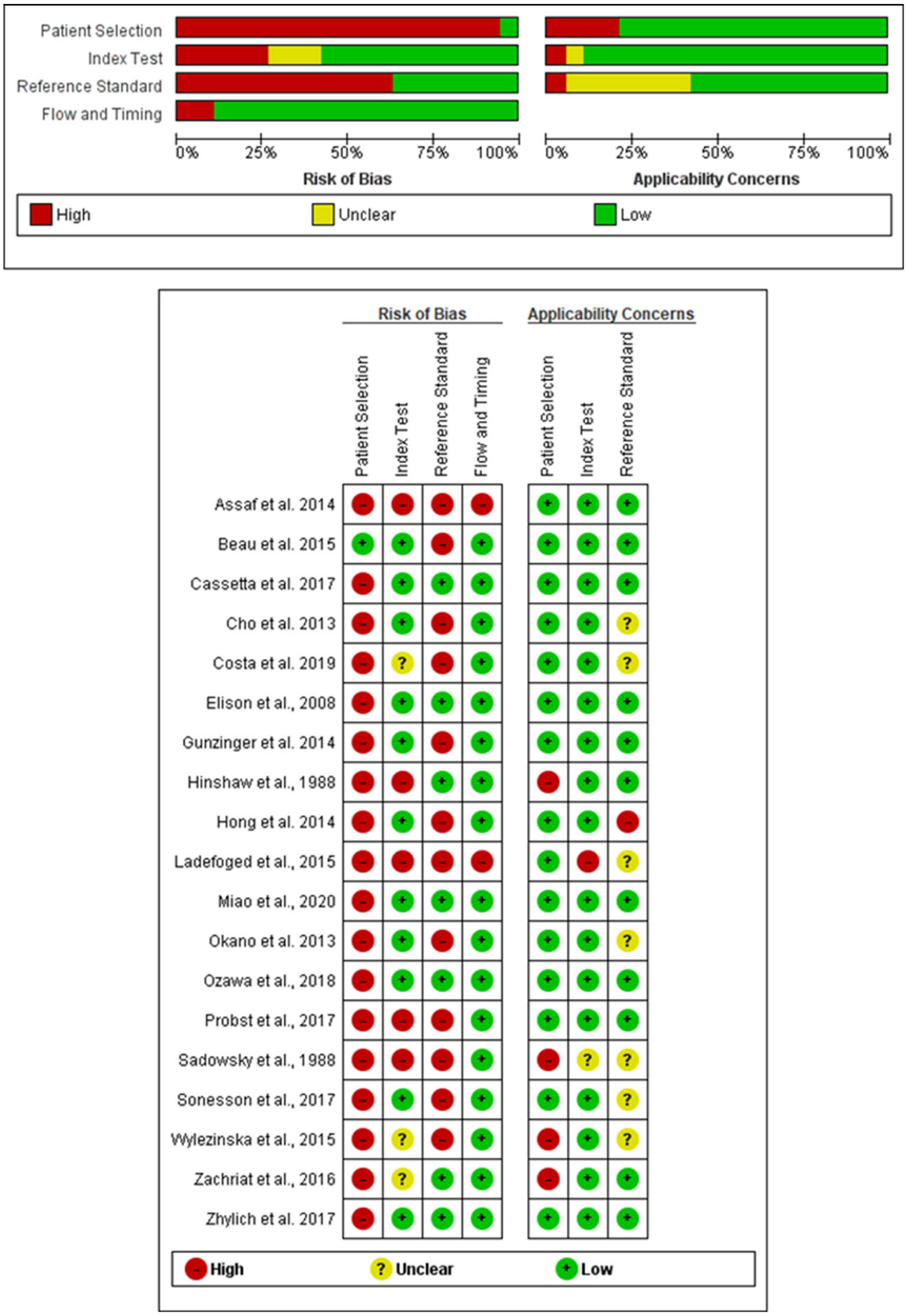

Figure 2 Risk of bias within studies (QUADAS-2).

good.[23,27,28,31,33] Likewise, imaging in temporomandibular joint varied between non-diagnostic[22,25,35] and diagnostic.[23,33,34]

Retainers caused only moderate artifacts, which were restricted to a part of the oral cavity.[22,26,28,32,34] Regardless of the evaluated site, titanium and ceramic brackets showed minimal localized artifacts, and images were considered suitable for diagnostic purposes.[22,27,28,33–35]

Artifacts in oral cavity caused by dental implants can be detrimental for the diagnosis of pathological conditions in this region.[38] However, two studies showed that the distinction of oral structures was feasible despite of the presence of artifacts.[29,32]

One study stated that the brain imaging was affected by dental implants artifacts, which hampered diagnostic evaluation.[24] Nonetheless, artifact reduction tools improved the image quality in both oral cavity and brain region.[32,36]

Two studies showed minimal or moderate artifacts caused by dental crowns, which did not hamper the diagnosis neither in.[24,30] Artifacts in brain region did not hamper the diagnosis.[24]

Table 5 Certainty assessment (GRADE)

Certainty assessment							
N^o of studies	*Study design*	*Risk of bias*	*Indirectness*	*Inconsistency*	*Imprecision*	*Other considerations*	*Certainty of evidence*
19	Cross-sectional	seriousa	not serious	not serious	seriousb	none	⊕⊕OO low

[a]Most studies did not take confounding factors in consideration.
[b]Imaging protocol and evaluation site differed among studies.

Quality of evidence assessment

Certainty assessed by GRADE was considered low due to the risk of bias and heterogeneity of the studies (Table 5).

Discussion

According to the findings of this review, dental materials were capable of producing artifacts. Whereas artifacts caused by orthodontic appliances are well described in literature, studies evaluating dental implants and restorations artifacts are scarce.[41–46] Indeed, respecting orthodontic appliances, stainless steel brackets were associated with greater artifacts in MR imaging of head and neck.

In general, the oral cavity was the site most involved, irrespective of the dental device evaluated. Nonetheless, not only diagnoses within the oral cavity but also those of the brain and craniofacial structures were affected. Detrimental effects on diagnosis were dependent on the extension and position of artifacts. In cases in which artifacts were considered small, diagnosis and delimitation of anatomical structures were possible.[24,37] Nonetheless, Hong et al. (2014) showed that, when dental devices were located close to tumors, artifacts were harmful to the accuracy of images.[40]

There was a consensus in literature that artifacts caused by titanium and ceramic materials were limited to the oral cavity, whereas stainless steel alloy strongly affected the magnetic field. It is well known that ferromagnetic substances are responsible for distortion of the magnetic field and subsequent signal loss.[11] Since stainless steel is composed of ferromagnetic metals such as Nickel and Chromium, distortion of the magnetic field is expected. This tendency decreases for diamagnetic and paramagnetic materials, as gold or titanium, respectively.[24]

Material features, as its location, size, and thickness affected the artifacts extension.[14] Since orthodontic appliances are placed on a large region of the oral cavity, the main concern is whether artifact severity and extension hamper the diagnosis. In accordance with the findings, stainless steel brackets caused artifacts on different anatomical regions, especially in combination with arch wires.[22,23] In this sense, the removal of orthodontic appliances prior to the MRI may be required.[23]

In accordance with the findings, stainless steel brackets were related to artifacts in different anatomical regions. The severity of artifact increased when these brackets were used in combination with arch wires.[22,23] In this regard, the removal of orthodontic appliances prior to the MRI may be required.[23]

In regard to dental implants, artifacts tended to be localized on the oral cavity and hampered the assessment of adjacent structures. However, susceptibility artifacts were also observed in brain imaging. It is suggested that different treatment protocols and implant features affect the appearance and extension of artifacts. Although these factors were extensively assessed in *in-vitro* studies,[47–49] clinical studies lacked to provide information regarding the influence of dental implant treatment on MR diagnosis. Likewise, there is insufficient data to enable a conclusion to be reached regarding prosthodontics materials, since only few studies assessed artifacts caused by gold crowns.

Not only the dental material but also the magnetic field strength, imaging purpose and MRI sequences influence the appearance of artifacts. Currently, conventional techniques are available to reduce artifacts, as the use of a lower field strength or a turbo-spin-echo sequence. In accordance to the literature, studies showed larger artifacts for 3T MRI in comparison to 1.5T MRI.[32,34] In addition, a turbo-spin-echo (TSE) sequence decreased artifacts in comparison to a gradient-echo sequence (GRE).[15,32]

Specific MRI sequences for artifact reduction, as slice encoding metal artifact correction (SEMAC) and view angle tilting (VAT) have been showing to improve image quality.[14,32] VAT reduces geometric in-plane distortions, and it is correlated with an increase on image blurring. Conversely, SEMAC is applied to correct through-plane distortions, but it requires an increased scan time.[32] When imaging the head and neck, a reduced scan time is preferable, since movement artifacts may appear in occurrence of swallowing and involuntary movements. Thus, the benefits of each technique must be carefully evaluated.

This review present some limitations. Different MRI systems and protocols resulted in controversial results, which hampered a quantitative analysis of the findings. Furthermore, other dental materials, as endodontic or osteosynthesis material, were not included in these results.

In summary, the appearance of susceptibility artifacts, and its influence on diagnosis may be associated with dental material features and MR parameters. The purpose of diagnosis and the site to be evaluated should be also taken in consideration to estimate the severity of unintended effects.

Conclusion

Artifacts caused by orthodontic appliances affected the diagnosis in oral cavity and craniofacial structures. Data regarding dental implants and prosthodontics restorations were scarce and inconclusive.

Funding

Open Access funding enabled and organized by Projekt DEAL.

REFERENCES

1. Suga H, Yanagida A, Kanazawa N, Ohara H, Kitagawa T, Hayashi M, et al. Status epilepticus suspected autoimmune: Neuronal surface antibodies and main clinical features. *Epilepsia* 2021; **62**: 2719–31. https://doi.org/10.1111/epi.17055
2. Janas AM, Qin F, Hamilton S, Jiang B, Baier N, Wintermark M, et al. Diffuse Axonal Injury Grade on Early MRI is Associated with Worse Outcome in Children with Moderate-Severe Traumatic Brain Injury. *Neurocrit Care* 2021. https://doi.org/10.1007/s12028-021-01336-8
3. McKinney AM, Lohman BD, Sarikaya B, Benson M, Lee MS, Benson MT. Accuracy of routine fat-suppressed FLAIR and diffusion-weighted images in detecting clinically evident acute optic neuritis. *Acta Radiol* 2013; **54**: 455–61. https://doi.org/10.1177/0284185113475444
4. Sepulveda I, Alzerreca J, Villalobos P, Ulloa JP. Giant Cell Tumor of the Temporal Bone With Skull Base and Middle Ear Extension. *J Med Cases* 2021; **12**: 149–51. https://doi.org/10.14740/jmc3627
5. Devaraja K, Godkhindi VM, Bhandarkar AM. First branchial cleft anomaly extending to parapharyngeal space. *BMJ Case Rep* 2021; **14**(8): e244842. https://doi.org/10.1136/bcr-2021-244842
6. Li M, Yuan Z, Tang Z. The accuracy of magnetic resonance imaging to measure the depth of invasion in oral tongue cancer: a systematic review and meta-analysis. *Int J Oral Maxillofac Surg* 2021; 00260–65.
7. Reda R, Zanza A, Mazzoni A, Cicconetti A, Testarelli L, Di Nardo D. An Update of the Possible Applications of Magnetic Resonance Imaging (MRI) in Dentistry: A Literature Review. *J Imaging* 2021; **7**(5): 75. https://doi.org/10.3390/jimaging7050075
8. Mercado F, Mukaddam K, Filippi A, Bieri OP, Lambrecht TJ, Kühl S. Fully Digitally Guided Implant Surgery Based on Magnetic Resonance Imaging. *Int J Oral Maxillofac Implants* 2019; **34**: 529–34. https://doi.org/10.11607/jomi.7076
9. Flügge T, Ludwig U, Hövener JB, Kohal R, Wismeijer D, Nelson K. Virtual implant planning and fully guided implant surgery using magnetic resonance imaging-Proof of principle. *Clin Oral Implants Res* 2020; **31**: 575–83. https://doi.org/10.1111/clr.13592
10. Wanner L, Ludwig U, Hövener JB, Nelson K, Flügge T. Magnetic resonance imaging-a diagnostic tool for postoperative evaluation of dental implants: a case report. *Oral Surg Oral Med Oral Pathol Oral Radiol* 2018; **125**: e103-7. https://doi.org/10.1016/j.oooo.2018.01.005
11. Graves MJ, Mitchell DG. Body MRI artifacts in clinical practice: a physicist's and radiologist's perspective. *J Magn Reson Imaging* 2013; **38**: 269–87. https://doi.org/10.1002/jmri.24288
12. Duttenhoefer F, Mertens ME, Vizkelety J, Gremse F, Stadelmann VA, Sauerbier S. Magnetic resonance imaging in zirconia-based dental implantology. *Clin Oral Implants Res* 2015; **26**: 1195–1202. https://doi.org/10.1111/clr.12430
13. Bohner L, Meier N, Gremse F, Tortamano P, Kleinheinz J, Hanisch M. Magnetic resonance imaging artifacts produced by dental implants with different geometries. *Dentomaxillofac Radiol* 2020; **49**(8): 20200121. https://doi.org/10.1259/dmfr.20200121
14. Rendenbach C, Schoellchen M, Bueschel J, Gauer T, Sedlacik J, Kutzner D, et al. Evaluation and reduction of magnetic resonance imaging artefacts induced by distinct plates for osseous fixation: an in vitro study. *Dentomaxillofac Radiol* 2018; **47**(7): 20170361. https://doi.org/10.1259/dmfr.20170361
15. Zachriat C, Asbach P, Blankenstein KI, Peroz I, Blankenstein FH. MRI with intraoral orthodontic appliance-a comparative in vitro and in vivo study of image artefacts at 1.5 T. *Dentomaxillofac Radiol* 2015; **44**(6): 20140416. https://doi.org/10.1259/dmfr.20140416
16. Erasmus LJ, Hurter D, Naude M, Kritzinger HG, Acho S. A short overview of MRI artefacts. *S Afr J Radiol* 2004; **8**: 13. https://doi.org/10.4102/sajr.v8i2.127
17. Hilgenfeld T, Prager M, Heil A, Schwindling FS, Nittka M, Grodzki D, et al. MSVAT-SPACE and SEMAC sequences for metal artefact reduction in dental MR imaging. *Eur Radiol* 2017; **27**: 5104–12. https://doi.org/10.1007/s00330-017-4901-1
18. Moher D, Shamseer L, Clarke M, et al. Preferred reporting items for systematic review and meta-analysis protocols (PRISMAP) 2015 statement. *Rev Esp Nutr Humana Diet* 2016; **20**: 148–60.
19. Booth A, Clarke M, Ghersi D, Moher D, Petticrew M, Stewart L, et al. An international registry of systematic-review protocols. *Lancet* 2011; **377**: 108–9. https://doi.org/10.1016/S0140-6736(10)60903-8
20. Whiting PF, Rutjes AWS, Westwood ME, Mallett S, Deeks JJ, Reitsma JB, et al. QUADAS-2: a revised tool for the quality assessment of diagnostic accuracy studies. *Ann Intern Med* 2011; **155**: 529–36. https://doi.org/10.7326/0003-4819-155-8-201110180-00009
21. Manheimer E. Summary of Findings Tables: Presenting the Main Findings of Cochrane Complementary and Alternative Medicine-related Reviews in a Transparent and Simple Tabular Format. *Glob Adv Health Med* 2012; **1**: 90–91. https://doi.org/10.7453/gahmj.2012.1.1.015
22. Beau A, Bossard D, Gebeile-Chauty S. Magnetic resonance imaging artefacts and fixed orthodontic attachments. *Eur J Orthod* 2015; **37**: 105–10. https://doi.org/10.1093/ejo/cju020
23. Cassetta M, Pranno N, Stasolla A, Orsogna N, Fierro D, Cavallini C, et al. The effects of a common stainless steel orthodontic bracket on the diagnostic quality of cranial and cervical 3T- MR images: a prospective, case-control study. *Dentomaxillofac Radiol* 2017; **46**(6): 20170051. https://doi.org/10.1259/dmfr.20170051
24. Costa ALF, Appenzeller S, Yasuda C-L, Pereira FR, Zanardi VA, Cendes F. Artifacts in brain magnetic resonance imaging due to metallic dental objects. *Med Oral Patol Oral Cir Bucal* 2009; **14**: E278-82.
25. Okano Y, Yamashiro M, Kaneda T, Kasai K. Magnetic resonance imaging diagnosis of the temporomandibular joint in patients with orthodontic appliances. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 2003; **95**: 255–63. https://doi.org/10.1067/moe.2003.37
26. Ozawa E, Honda EI, Parakonthun KN, Ohmori H, Shimazaki K, Kurabayashi T, et al. Influence of orthodontic appliance-derived artifacts on 3-T MRI movies. *Prog Orthod* 2018; **19**(1): 7. https://doi.org/10.1186/s40510-018-0204-6
27. Elison JM, Leggitt VL, Thomson M, Oyoyo U, Wycliffe ND. Influence of common orthodontic appliances on the diagnostic quality of cranial magnetic resonance images. *Am J Orthod Dentofacial Orthop* 2008; **134**: 563–72. https://doi.org/10.1016/j.ajodo.2006.10.038
28. Zhylich D, Krishnan P, Muthusami P, Rayner T, Shroff M, Doria A, et al. Effects of orthodontic appliances on the diagnostic quality of magnetic resonance images of the head. *Am J Orthod Dentofacial Orthop* 2017; **151**: 484–99. https://doi.org/10.1016/j.ajodo.2016.07.020
29. Assaf AT, Zrnc TA, Remus CC, Schönfeld M, Habermann CR, Riecke B, et al. Evaluation of four different optimized magnetic-

resonance-imaging sequences for visualization of dental and maxillo-mandibular structures at 3 T. *J Craniomaxillofac Surg* 2014; **42**: 1356–63. https://doi.org/10.1016/j.jcms.2014.03.026
30. Hinshaw DB, Holshouser BA, Engstrom HI, Tjan AH, Christiansen EL, Catelli WF. Dental material artifacts on MR images. *Radiology* 1988; **166**: 777–79. https://doi.org/10.1148/radiology.166.3.3340777
31. Miao X, Wu Y, Liu D, Jiang H, Woods D, Stern MT, et al. Whole-Brain Functional and Diffusion Tensor MRI in Human Participants with Metallic Orthodontic Braces. *Radiology* 2020; **294**: 149–57. https://doi.org/10.1148/radiol.2019190070
32. Probst M, Richter V, Weitz J, Kirschke JS, Ganter C, Troeltzsch M, et al. Magnetic resonance imaging of the inferior alveolar nerve with special regard to metal artifact reduction. *J Craniomaxillofac Surg* 2017; **45**: 558–69. https://doi.org/10.1016/j.jcms.2017.01.009
33. Sadowsky PL, Bernreuter W, Lakshminarayanan AV, Kenney P. Orthodontic appliances and magnetic resonance imaging of the brain and temporomandibular joint. *Angle Orthod* 1988; **58**: 9–20. https://doi.org/10.1043/0003-3219(1988)058<0009:OAAMRI>2.0.CO;2
34. Sonesson M, Al-Qabandi F, Månsson S, Abdulraheem S, Bondemark L, Hellén-Halme K. Orthodontic appliances and MR image artefacts: An exploratory in vitro and in vivo study using 1.5-T and 3-T scanners. *Imaging Sci Dent* 2021; **51**: 63–71. https://doi.org/10.5624/isd.20200199
35. Wylezinska M, Pinkstone M, Hay N, Scott AD, Birch MJ, Miquel ME. Impact of orthodontic appliances on the quality of craniofacial anatomical magnetic resonance imaging and real-time speech imaging. *Eur J Orthod* 2015; **37**: 610–17. https://doi.org/10.1093/ejo/cju103
36. Cho JH, Lee HK, Yang HJ, Lee GW, Park YS, Chung WK. A comparative quantitative analysis of magnetic susceptibility artifacts in echo planar and PROPELLER diffusion-weighted images. *Journal of the Korean Physical Society* 2013; **62**: 358–64. https://doi.org/10.3938/jkps.62.358
37. Gunzinger JM, Delso G, Boss A, Porto M, Davison H, von Schulthess GK, et al. Metal artifact reduction in patients with dental implants using multispectral three-dimensional data acquisition for hybrid PET/MRI. *EJNMMI Phys* 2014; **1**: 102. https://doi.org/10.1186/s40658-014-0102-z
38. Ladefoged CN, Hansen AE, Keller SH, Fischer BM, Rasmussen JH, Law I, et al. Dental artifacts in the head and neck region: implications for Dixon-based attenuation correction in PET/MR. *EJNMMI Phys* 2015; **2**: 8. https://doi.org/10.1186/s40658-015-0112-5
39. Hilgenfeld T, Prager M, Schwindling FS, Nittka M, Rammelsberg P, Bendszus M, et al. MSVAT-SPACE-STIR and SEMAC-STIR for Reduction of Metallic Artifacts in 3T Head and Neck MRI. *AJNR Am J Neuroradiol* 2018; **39**: 1322–29. https://doi.org/10.3174/ajnr.A5678
40. Hong HR, Jin S, Koo HJ, Roh J-L, Kim JS, Cho K-J, et al. Clinical values of 18F-FDG PET/CT in oral cavity cancer with dental artifacts on CT or MRI . *J Surg Oncol* 2014; **110**: 696–701. https://doi.org/10.1002/jso.23691
41. Roser C, Hilgenfeld T, Sen S, Badrow T, Zingler S, Heiland S, et al. Evaluation of magnetic resonance imaging artifacts caused by fixed orthodontic CAD/CAM retainers-an in vitro study. *Clin Oral Invest* 2020; **25**: 1423–31. https://doi.org/10.1007/s00784-020-03450-x
42. Shafiei F, Honda E, Takahashi H, Sasaki T. Artifacts from dental casting alloys in magnetic resonance imaging. *J Dent Res* 2003; **82**: 602–6. https://doi.org/10.1177/154405910308200806
43. Shalish M, Dykstein N, Friedlander-Barenboim S, Ben-David E, Gomori JM, Chaushu S. Influence of common fixed retainers on the diagnostic quality of cranial magnetic resonance images. *American Journal of Orthodontics and Dentofacial Orthopedics* 2015; **147**: 604–9. https://doi.org/10.1016/j.ajodo.2014.11.022
44. Patel A, Bhavra GS, O'Neill JR. MRI scanning and orthodontics. *J Orthod* 2006; **33**: 246–49. https://doi.org/10.1179/146531205225021726
45. Touska P, Connor SEJ. Recent advances in MRI of the head and neck, skull base and cranial nerves: new and evolving sequences, analyses and clinical applications. *Br J Radiol* 2019; **92**(1104): 20190513. https://doi.org/10.1259/bjr.20190513
46. Harris TMJ, Faridrad MR, Dickson JAS. The benefits of aesthetic orthodontic brackets in patients requiring multiple MRI scanning. *J Orthod* 2006; **33**: 90–94. https://doi.org/10.1179/146531205225021465
47. Smeets R, Schöllchen M, Gauer T, Aarabi G, Assaf AT, Rendenbach C, et al. Artefacts in multimodal imaging of titanium, zirconium and binary titanium-zirconium alloy dental implants: an in vitro study. *Dentomaxillofac Radiol* 2017; **46**(2): 20160267. https://doi.org/10.1259/dmfr.20160267
48. Hilgenfeld T, Prager M, Schwindling FS, Heil A, Kuchenbecker S, Rammelsberg P, et al. Artefacts of implant-supported single crowns - Impact of material composition on artefact volume on dental MRI. *Eur J Oral Implantol* 2016; **9**: 301–8.
49. Demirturk Kocasarac H, Ustaoglu G, Bayrak S, Katkar R, Geha H, Deahl ST, et al. Evaluation of artifacts generated by titanium, zirconium, and titanium-zirconium alloy dental implants on MRI, CT, and CBCT images: A phantom study. *Oral Surg Oral Med Oral Pathol Oral Radiol* 2019; **127**: 535–44. https://doi.org/10.1016/j.oooo.2019.01.074