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Preoperative radiological evaluation of missing single teeth: A review

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Aims: Missing single teeth can be treated in several ways and preoperative radiological evaluation varies accordingly. The main area of controversy relates to the need for cross-sectional imaging in the context of implant treatment. In this context, the aim of the systematic component of this review was to determine whether the use of additional cross-sectional imaging has any impact on diagnostic thinking, treatment planning or outcome, compared with conventional imaging alone. An additional aim was to present information relating to diagnostic efficacy, dose of radiation, economic aspects of imaging and selection criteria.
Materials and methods: PubMed/MEDLINE, OVID/Embase and the Cochrane central register of controlled trials were searched up to and including June 2015. Studies were eligible for inclusion if they compared the impact of conventional and cross-sectional imaging when placing implants. Quality assessment of studies was performed. Synthesis was qualitative.
Results: Twelve studies were included, all of which had a 'before-after' design. Only three of these were limited to single implant treatments with none limited to immediate implants. There were methodological problems with most of the studies and results were sometimes contradictory regarding the impact of cross-sectional imaging.
Conclusions: It is tentatively suggested that cross-sectional imaging may not be required in straightforward, unchallenging, cases of missing single teeth being considered for implant treatment. Beyond this, no strong evidence exists to inform the choice of imaging. Existing guidelines on preoperative imaging for missing single teeth are not unanimous in their recommendations, either for implant or non-implant treatments.

Conflict-of-interest statement: *The authors declare that they are authors of one paper included in the systematic review part of this paper. Otherwise there are no conflicts of interest.*

■ Introduction

Treatment planning for replacement of missing single teeth requires a thorough history and clinical examination, usually supplemented by radiological examination. It is a fundamental principle of radiation protection that all clinical uses of ionising radiation must be justified in advance at the individual patient level[1]. Furthermore, some radiological modalities can be expensive, particularly those typically used in more complex treatments such as implants. Therefore, from both radiation protection and economic perspectives, it is important to use radiological diagnostic procedures only when it is appropriate to do so. Following justification, all exposures to ionising radiation must be optimised so that patient doses are kept as low as reasonably achievable, taking into account image quality requirements[1]. The diagnostic efficacy of imaging is a key consideration and the hierarchy developed by Fryback and Thornbury[2] is widely used to assess it (Table 1). In this hierarchy, a satisfactory performance at lower levels does not mean that efficacy is guaranteed at the higher levels. For example, a technically excellent diagnostic imaging test (Level 1) may produce more accurate diagnosis (Level 2), but may not alter patient management (Level 4) or patient outcome (Level 5). Thus, the choice of imaging for patients should ideally be informed by higher level evidence which addresses impact (Levels 3 or higher).

For most of the latter half of the twentieth century, the clinician and/or surgeon had limited choices for imaging: mainly 'conventional' radiography (intraoral, panoramic and cephalometric), supplemented by possible access to conventional or computed tomography (CT) radiograph systems. Today, cone beam computed tomography (CBCT) offers easy access to cross-sectional imaging, with particular relevance to implant placement. There has, however, been concern about the potential for overuse of this modality on the grounds of radiation dose and financial costs[3].

The treatment modalities for replacement of missing single teeth range from simple to complex procedures. Imaging should be prescribed which provides adequate diagnostic efficacy at the lowest financial cost and with the least exposure to radiation. This process is aided by the availability of clinical guidelines, known as referral criteria, selection criteria or appropriateness criteria. These criteria are not protocols that must be followed for all patients, but are "a concept of good practice against which the needs of the individual patient can be considered"[4].

Selection criteria for dental radiology, when treating missing single teeth using non-implant solutions, are well established[5-7]. When planning oral endosseous implants, however, there is disagreement between the guidelines. Some suggest that cross-sectional imaging is required in all cases when implants are planned[8-11], while others suggest selected use[3,7,12-20] or offer equivocal statements[21-23]. These differences have been highlighted in recent systematic reviews[24,25]. It is notable that existing guidelines do not look specifically at the single tooth implant situation, which might present unique imaging needs and challenges, or at immediately placed implants in tooth sockets. There is, therefore, a need for systematic assessment of the relative diagnostic efficacies of conventional radiography and cross-sectional imaging, as part of implant planning, particularly at the higher levels of the Fryback and Thornbury hierarchy[2].

The broad question underlying this review was: what imaging techniques are appropriate as part of preoperative evaluation of missing single teeth? Nevertheless, the main area of controversy in preoperative radiological evaluation of missing single teeth is the appropriateness of cross-sectional imaging when planning implant placement. Consequently, the focused question addressed by this review was: does the use of additional cross-sectional imaging have any impact on diagnostic thinking, treatment planning or outcome compared with conventional imaging alone, in the preoperative evaluation of single missing teeth for implant treatment? This was addressed by a systematic review of the literature. The paper subsequently considers the preoperative radiological evaluation of missing single teeth in a wider context, including selection criteria.

■ Materials and methods

The design of this review was adapted from that used in a recently published systematic review[26], which addressed implants in the anterior mandible to support an overdenture. The research question, modified from those used previously, was: does the use of additional cross-sectional imaging have any impact on diagnostic thinking, treatment planning or outcome compared to conventional imaging alone, in the preoperative evaluation of single missing teeth for implant treatment? This matched levels 3, 4 and 5 of the hierarchy of efficacy as defined by Fryback & Thornbury[2] (Table 1). Lower level studies, concerned with technical efficacy or diagnostic accuracy efficacy, were not included. Similarly, studies which analysed only the higher level of societal efficacy were excluded.

Inclusion criteria

- Human *in vivo* studies or *in vitro* human simulation studies where implants were planned.
- Comparison between cross-sectional imaging, of any type (tomography, CBCT, CT and Magnetic Resonance Imaging [MRI]), and conventional, two-dimensional radiography prior to implant placement.
- The outcome had to be classifiable as diagnostic thinking, therapeutic efficacy or patient outcome (Table 1).
- Permissible study designs were before-after studies, randomised controlled studies or other observational study designs.
- Studies were included where the primary purpose was cross-sectional imaging for assessment prior to implant placement rather than being primarily for the construction of a computer- generated surgical guide.
- Studies in the English language or with an English language abstract.
- The following publication types were considered: peer-reviewed journals, non-peer-reviewed journals, reports, book chapters, conference abstracts, theses, informal reports and on-going studies where complete data were available.

While the review was focused on preoperative imaging of missing single teeth, previous experience[27] suggested that the volume of literature was likely to be limited and often not restricted to specific clinical situations such as single missing teeth. Consequently, an a priori decision was taken not to restrict the review to studies solely dealing with single implants.

Search strategy

This replicated the previously performed strategy[27] exactly, but with the endpoint date extended from February 2013 to June 2015. Three bibliographic databases, PubMed/MEDLINE, OVID/Embase and the Cochrane central register of controlled trials were searched. Each allowed different search terms. The reference sections of relevant studies identified in the search of bibliographic databases were handsearched, and the references of clinical guideline publications listed in the reference sections of two recent reviews[24,26], were similarly handsearched.

Study selection

After removal of duplicates, two authors (KH and AMS) independently screened publications. First, titles and then abstracts were screened to exclude studies that were irrelevant. Finally, full texts of remaining publications were reviewed for eligibility. In cases where there was disagreement between the authors, or where either expressed doubt about whether the inclusion criteria were fully satisfied, a third reviewer (AMG) was involved.

Data extraction

Detailed assessment of each full paper was carried out independently by two reviewers (KH and AMS). Disagreements were resolved by subsequent discussion. Reviewers were not blinded to authors, institution or study results during the study selection process, as there was existing familiarity with most studies and blinding was not seen as essential[27]. The data extraction form developed by Shelley et al[26] was used.

Quality assessment

All included studies could be classified as having a 'before-after' design. Quality assessment was carried out by two reviewers (AMS and KH) independently, using the tool used by Shelley et al[26], which is an adaptation of a previous design[28]. This tool summarises overall quality assessment using a visual analogue scale. After independent assessment, the two reviewers met to compare quality assessments and came to an agreement. Any disagreement was resolved by the involvement of a third reviewer. To limit the risk of bias in the quality assessment, where any of the authors of the current review were listed as an author of included publications, quality assessment was performed independently by two reviewers (KH, AMS and, if required, one or two alternative reviewers).

Synthesis

Tables were constructed of study characteristics, outcomes and quality assessment. For each included

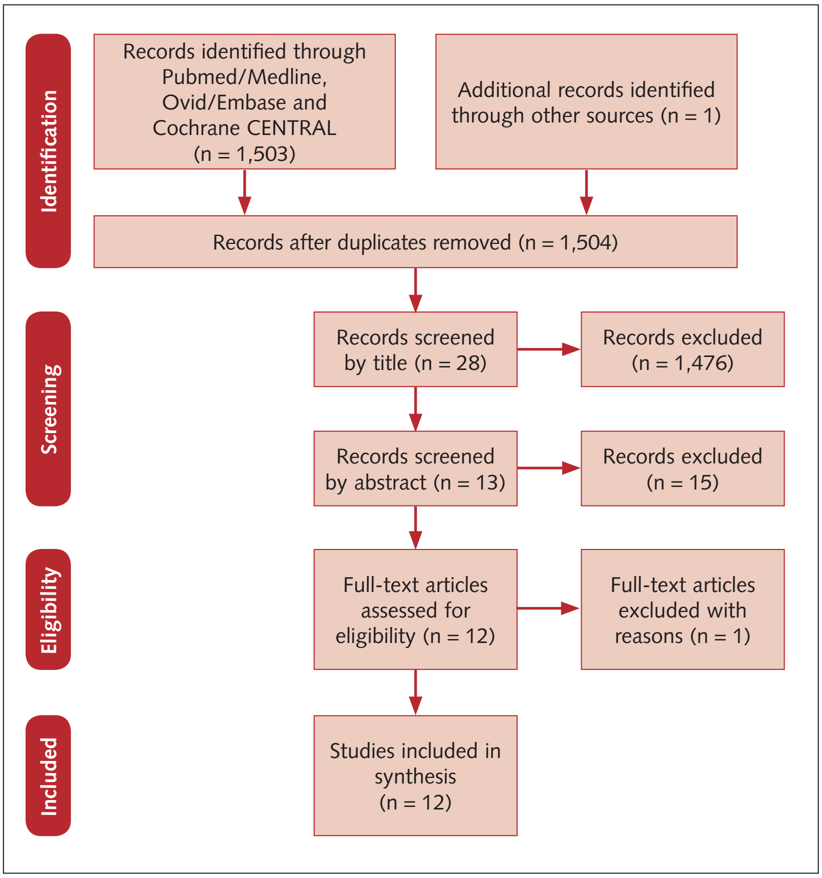

Fig 1 PRISMA[29] flow chart showing the results of searches and study selection.

study, the two authors agreed on whether or not the availability of cross-sectional imaging led to a change in diagnostic thinking, treatment planning or outcome. Pooled quantitative analysis was not possible because of the small number of identified studies and their heterogeneity. Analysis, therefore, was qualitative only.

Results

Figure 1 shows the flow of publications identified through the searches. Twelve articles were included and underwent data extraction and quality assessment[30-41]. The authors of the current review were listed authors of one included study[41]. Of the twelve included studies, only three were studies limited to implants which were planned for single missing teeth[31,34,37]. At least three other studies included some cases of implants replacing single missing teeth, or could reasonably be assumed to have done so, but the data relating to these could not be extracted for separate analysis[32,33,38]. No studies differentiated between immediate, early or delayed implant cases. All 12 included studies were judged to be at Level 4 of Fryback and Thornbury's hierarchy of diagnostic efficacy[2], although one[37] stated that their study was at Level 3 (diagnostic thinking efficacy), although in our view, the design matched the definition of Level 4 listed in Table 1. Another study[41] had an element that arguably could have been judged as Level 5, as the authors recorded perforations when performing osteotomy for implants in an anthropomorphic phantom. A pragmatic decision was made to evaluate this study with the others, as studies of therapeutic efficacy.

Table 2 shows the subjective quality assessments for the studies using the visual analogue scale. The quality of the studies was judged as variable but was frequently low. The reasons for these low ratings were many, but typical problems included single observer studies[31,32,35,38] , the results of which are unlikely to be translatable, and combining observations of multiple observers into average scores[33,37], which does not reflect real clinical practice. Sample sizes were sometimes very small[30,36]. Although some studies used selection criteria to narrow the focus onto particular patient and case types, notably Frei et al[32], who excluded challenging cases, other studies included study subjects that were of mixed difficulty[33,38,40]. Low quality scores were often related to vague or incomplete reporting of methods[40]. In some cases, the 'after' cross-sectional imaging was viewed without simultaneous availability of conventional radiographs[34,37] or clinical information, which limits the relevance to clinical practice. Finally, patient selection bias may also have been a problem[35,38].

Table 3 shows the main study characteristics of the twelve publications. There was a range of cross-sectional imaging, with spiral tomography being used in four studies[31-34] and CT in one study[30]. All other studies used CBCT; all studies published after 2011 did so. Panoramic radiographs were always used as conventional 'before' imaging, although intraoral radiography was added to panoramic imaging in some studies[31,33,35,40], while Shelley et al[41] added transymphyseal (lateral anterior mandible) radiographs[42].

Table 4 summarises the outcomes of the studies according to whether cross-sectional imaging had an

Table 1 The hierarchical model of efficacy of diagnostic imaging, according to Fryback and Thornbury[2], with some typical measures of analysis.

Efficacy level	Measures of analysis
Level 1: Technical efficacy	Resolution of line pairs Linear and angular measurement accuracy Contrast detail resolution Grey scale reproduction of true density differences Severity of artefacts
Level 2: Diagnostic accuracy efficacy	Sensitivity and specificity Positive and negative predictive values ROC curve areas
Level 3: Diagnostic thinking efficacy	Proportion of cases in a series in which image judged to be 'helpful' Difference in clinicians' subjective estimated diagnosis probabilities pre- and post-imaging in a case series
Level 4: Therapeutic efficacy	Proportion of cases in a series for which image judged to be 'helpful' in planning treatment Proportion of cases in which pre-imaging treatment plans were changed after imaging
Level 5: Patient outcome efficacy	Proportion of patients improved with the imaging test compared to without the imaging test Morbidity avoided by using imaging Change in oral health-related quality of life (OHRQoL) resulting from using imaging
Level 6: Societal efficacy	Benefit-cost analysis from a societal standpoint Cost-effectiveness analysis from a societal standpoint

impact on aspects of therapeutic efficacy. The impact of cross-sectional imaging on the selection of implant size (width and length) was addressed in eight studies. All reported some changes, although this was in the minority of cases for most studies[32,33,38,39]. In one of these, the availability of cross-sectional images changed the selected implant size in less than 4% of cases[32]. One study looked at multiple implant systems and cross-sectional imaging availability led to a change in implant size to varying degrees depending on the system used[37]. Only two studies reported a change in selected implant dimensions for a majority of cases[31,34]. In terms of trends looking at whether a change of implant dimensions (i.e. narrower/ wider and shorter/longer) were associated with the availability of cross-sectional imaging, no trends in any direction were seen in three studies[31,32,33], all of which used spiral tomography systems. A trend associated with shorter implant size when using cross-sectional images was seen in two studies[37,39]. Also there was a trend towards a narrower implant size being used in three studies[37,38,41], although this was only for challenging cases in the latter study[41]. One study, however, reported a trend in terms of longer and wider implants being selected[34].

Table 2 Subjective quality assessments on a visual analogue scale. Green suggests high quality and red suggests low quality.

Study	Quality assessment
Reddy et al[30]	✓
Schropp et al[31]	✓
Frei et al[32]	✓
Diniz et al[33]	✓
Fortin et al[34]	✓
Schropp et al[35]	✓
Baciut et al[36]	✓
Correa et al[37]	✓
Guerrero et al[39]	✓
Guerrero et al[40]	✓
Mello et al[38]	✓
Shelley et al[41]	✓

Those studies looking at the confidence of operators[30,36,39] reported an improvement with the availability of cross-sectional imaging. For all other outcomes measured in the included studies, there was either no measurable change or equivocal findings when cross-sectional imaging was available, with the exception of two studies[39,41]. Guerrero et al[39]

Table 3 Characteristics of the included studies; OPG: orthopantomograph.

Reference	Country Setting	No. of implants placed [No. of patients treated]	No. of evaluators	Site	'Before' imaging	'After' imaging	Summary of aim(s) of study
Reddy et al[30]	Not stated but probably USA	>10 [10]	4	Not stated	Panoramic	Medical multi-slice CT	For ten subjects the treatment was planned using panoramic images alone and panoramic plus CT images, and the aim of the study was to determine the validity of both examinations and the confidence of the investigators in treatment planning with these images
Schropp et al[31]	Hospital Denmark	46 [46]	1	All sites	Panoramic and periapical	Spiral tomography (Scanora)	The aim of this study was to evaluate the efficacy of conventional cross-sectional tomographic examination as an adjunct to panoramic and periapical examination in the prediction of the appropriate implant size (length and width) for treatment with single tooth implants
Frei et al[32]	Not stated but probably Switzerland	77 [50]	1	Posterior mandible	Panoramic	Spiral tomography (Cranex Tome)	To investigate whether cross-sectional imaging influences the planning and therapy of standard implant cases in the posterior mandible
Diniz et al[33]	Not stated but probably Brazil	113 [29]	2	All sites	Panoramic and periapical	Spiral tomography (Cranex Tome)	To investigate variation in the pre-surgical treatment planning after using conventional spiral tomography in addition to conventional radiographic exams
Schropp et al[34]	Hospital Denmark	121 [121]	3	All sites	Panoramic	Spiral tomography (Scanora)	To compare panoramic and conventional cross-sectional tomography for preoperative selection of implant size. The aim of the study was to evaluate in how many cases did the planned dimensions differ
Fortin et al[35]	Hospital France	301 [128]	1	Posterior maxilla	Intraoral or panoramic	CBCT (Newtom)	To determine the degree to which residual bone was underestimated on panoramics compared to CBCT To determine the degree to which the necessity for sinus grafting was overestimated on panoramics compared to CBCT
Baciut et al[36]	Hospital Romania	16 [13]	6	Posterior maxilla	Panoramic	Cone beam CT (Newtom 3G)	To compare clinical validity of panoramic and CBCT in preoperative planning of implants in combination with sinus grafting procedures
Correa et al[37]	Hospital Brazil	103 [71]	3	Upper premolar and lower molar	Digital panoramic (Cranex D)	CBCT (iCat)	To compare implant length and width planned with panoramic and CBCT views in four implant systems
Mello et al[38]	Hospital Brazil	95 [27]	1	All sites	Panoramic (Cranex Tome)	CBCT (iCat)	To investigate the impact of CBCT on implant planning and predication of final implant size
Guerrero et al[39]	Hospital Peru	619 [105]	4	All sites	Panoramic (OPG or Cranex Tome)	CBCT (Scanora or iCat)	To compare planning of implant placement based on panoramic and CBCT images To study the impact of the image data set on treatment planning
Guerrero et al[40]	Hospital Peru	365 [108]	5	All sites	Intraoral or panoramic	CBCT (iCat)	To determine the efficacy of prediction of the need for bone grafting and perioperative complications
Shelley et al[41]	Private Dental Practice UK	64 [4] (patient simulations)	8	Anterior mandible	Intraoral (transymphyseal) and panoramic	CBCT (3D Accuitomo)	To evaluate the impact of CBCT imaging when placing implants in the anterior edentulous mandible using a before-after study design

Table 4 Summary of the outcomes of the included studies according to whether cross-sectional imaging had an impact on aspects of treatment planning*.

	Selection of implant size	Surgical confidence	Necessity for bone grafting or other surgical procedures	Prediction of graft volume	Change in treatment plan	Mean implant length	Prediction of complications	Assessment of sinus morphology	Choice of treatment	Timing of treatment	Image quality	Perforation of lingual plate	Assessment of surgical difficulty
Reddy et al[30]		Improved				No significant difference							
Schropp et al[31]	Change in majority of cases. No trends												
Frei et al[32]	Change in small minority of cases. No trends				No difference in 96.1%								
Diniz et al[33]	Change in minority of cases. No trends		Equivocal										
Schropp et al[34]	Change in majority of cases. Trend to longer and wider implants												
Fortin et al[35]			Reduced using X-sectional										
Baciut et al[36]		Improved	No difference	No difference			No difference	No difference	No difference				
Correa et al[37]	Change in minority of cases. Trend to shorter and narrower implants												
Mello et al [38]	Change in minority of cases. Trend to narrower implants												
Guerrero et al[39]	Change in minority of cases. Trend of shorter and narrower implants in posterior regions	Improved									Improved		
Guerrero et al[40]			Equivocal				Equivocal						
Shelley et al[41]	Trend to narrower implants in "challenging" cases		No difference									No difference	More difficult

* In studies which suggested a difference after the availability of cross-sectional imaging, the results are highlighted in pink. In cases where no difference after cross-sectional imaging was found the results are highlighted in blue. Equivocal results are highlighted in grey.

reported an increase in subjective image quality for CBCT, compared with panoramic radiographs, while Shelley et al[41] found that challenging cases were perceived as more difficult after cross-sectional imaging was viewed.

■ Discussion

This systematic review demonstrated limited evidence for the efficacy of cross-sectional imaging when planning implant treatment for missing single teeth. Only three studies, with some shared authorship, specifically dealt with this clinical context and should be considered in some depth[31,34,37]. The two earlier studies used spiral tomography, although the widely available method of cross-sectional imaging is currently CBCT. There are differences in image quality between tomography and CBCT and the results of these studies may not be automatically transferable in terms of the contemporary situation. The results of these studies have some methodological limitations in terms of their wider applicability; one was a single observer study[31] with a consequently high risk of bias due to potential individual idiosyncrasies, while another used mean values of three observers[34]. The most recent study, in contrast, presented data for individual observers[37]. One methodological feature of two of these studies[34,37] is that they considered selection of implants based either on panoramic radiographs alone or cross-sectional images alone. This is different from the clinical situation, in which all available images would be used together with the findings of the clinical examination. This point was recognised by the authors, who emphasised that their studies were aimed at understanding the relative contributions of different images to treatment planning rather than to identifying selection criteria.

Schropp et al[31], in a study of 46 implant sites, found that the availability of cross-sectional images led to a change in either selected implant length or width in 70% of cases and concluded that preoperative cross-sectional imaging was indicated for single implant treatments. Length was altered more than width, with a slight tendency towards selecting longer and narrower implants. Putting aside the issue of this being a single-surgeon study, there are other potential criticisms. Magnification factors for the radiographs and tomograms were assumed rather than controlled using a reference object. This potentially introduced a systematic error. The implant dimensions actually used at surgery were compared with those planned using conventional radiography alone or with the addition of tomography and found significantly greater agreement with surgery, for the latter. However, it should be noted that the choice of implant size at surgery was determined by the surgeon and was changed in a few cases even when tomography was available. It could be argued therefore, that the imaging was not of primary importance when the surgical findings were pre-eminent in selecting implant dimensions.

Schropp et al[34] found differences in the selection of implant size based on tomography or panoramic images in the overwhelming majority of cases. The impact on choice of length and width agreed broadly with the results of their previous study[31]. With cross-sectional imaging there was a tendency to choose longer implants overall, although shorter implants were selected in a smaller proportion of cases. The findings for implant width are less clear. Overall data showed a fairly even split between selecting wider or narrower implants when using tomograms, but the authors also reported a marked tendency to select narrower implants in both maxillary and mandibular anterior regions (in 53% and 44% of cases, respectively), when tomography was used. However it is not stated, in what proportion of these cases was a wider implant chosen. Furthermore, the authors did not provide details of absolute implant size differences between imaging methods and presented only qualitative changes (i.e. shorter, longer, wider and narrower). They did, however, demonstrate that the impact of basing selection of implant size on tomographs or panoramic images differed according to the implant system used. In the study where a system with fewer available implant size options was used, where in this case the Straumann system was adopted, the impact of the imaging technique was less.

The study of Correa et al[37] has the advantage of a larger sample size of patients and implant sites. The cross-sectional imaging method selected was CBCT, which provides greater contemporary relevance. This study considered implant dimensions planned using three image types: conventional panoramic radiographs, panoramic images reconstructed from CBCT data and cross-sectional images reconstructed from CBCT data. They reported that the majority of the implants changed to a smaller size, in either width or length, when the planning was made using CBCT cross-sectional images and that the length was changed more often than the width. The authors state that results for width were in agreement with the results of Schropp et al[34], which were different for length, since the earlier study reported a shift towards longer implants, where tomographic images were available, with no trend in either direction, for diameter. The reasons for the difference between studies cannot be answered with any confidence. It may reflect any one, or a combination of factors, including a change in imaging modality, differences between observers or differences in case selection. For example, one study was limited to posterior teeth[37] while the other had a large proportion of maxillary anterior teeth[34].

If the inclusion criteria for this review had been strictly limited to studies where implants for missing single teeth could be considered in isolation, these three studies[31,34,37] would have been the only ones considered. A decision was made to include a broader range of studies in the expectation that even a more comprehensive strategy would not identify a large body of literature. The question that must be asked however is, how different is implant planning and treatment for a single missing tooth compared with multiple implant cases? The answer must be very little in terms of the jaw anatomy, although it seems reasonable to assume that the presence of teeth next to the space might limit ridge resorption after extraction compared with a wider edentulous space. It is also possible that the roots of adjacent teeth may impinge on a potential osteotomy site for single implant placement. Significant differences might be encountered, however, in the imaging. The presence of adjacent teeth may preclude the use of some imaging options (e.g. lateral views) because of superimposition. If teeth adjacent to the single missing tooth space are heavily restored, with root fillings and metal posts, then the artefact may make image quality poor with CBCT or CT. Overall, it seemed reasonable to keep the inclusion criteria quite wide, so long as these potential weaknesses were borne in mind.

When all included studies are considered, it is worth highlighting the variability in the methodology, some of which had a major impact on the quality assessment. None can be considered as having a sufficiently faultless design in providing strong evidence. Some studies included a clearly insufficient number of observers making image assessments[33,35,38]. Some studies, such as Mello et al[38] had implant cases that were well distributed around the jaws, however other studies gave no detail of the distribution[30,33], while others were skewed to certain regions or highly specific in their design[32,40,42]. As some studies show differences in outcomes according to anatomical site[31], it is important not to extrapolate results as being generally applicable throughout the oral cavity. Surgical validation of the image-based implant planning was sometimes used[30,32,38], although not strictly required for a before-after study design, it does offer an independent standard against which choices based on imaging can be compared. Nonetheless, it is of particular interest that in these studies there were cases of the surgically selected implant being different to that chosen by either conventional or cross-sectional imaging[32,38]. It also raises questions about the role and importance of preoperative imaging when final decisions about implant size are made at the time of implant placement.

It was hard to identify any clear message from the studies regarding the impact of cross-sectional images on treatment planning (Table 4). As far as implant dimensions are concerned, most studies report that the availability of cross-sectional images leads to a change in planned implant size, although the recent study of Guererro et al[39] stands out in showing this for only a minority of a large sample of implants, mainly in the posterior parts of the jaws, with a tendency towards selecting shorter and narrower implants when CBCT was available. Only the studies of Schropp et al[31,34] report a change in implant size for the majority of cases when cross-sectional images are used. In both of these studies, the cross-sectional imaging technique was conventional tomography. In terms of any trends towards changes in implant dimensions, some studies show none, either for implant length or width while the others give conflicting findings (Table 4).

In these studies, the importance of selection of implant size alone may be questioned. It is clearly possible to place the same size of implant in either a favourable or unfavourable position. Differences in implant size selection alone, therefore, should not necessarily be interpreted as justification for three-dimensional imaging. The study of Shelley et al[41] stands out from the others in that it was a laboratory study using anthropomorphic phantoms and extended the scope of the work to include both Fryback and Thornbury's Level 4 and Level 5 (outcome efficacy), in the form of recording perforations of the lingual surface of the mandible, when placing implants in the parasymphyseal region. A critical aspect of successful implant treatment is optimal position in relation to the three dimensions. Failure to achieve this can lead to significant problems, ranging from damage to adjacent teeth, through to permanent nerve damage or significant haemorrhage. Their study showed that in 'regular' cases CBCT had no impact on implant selection or the incidence of cortical perforation, but that in 'challenging' cases there was a trend to selecting narrower implants. Differences in cortical perforations before and after the availability of three-dimensional imaging were not statistically significant. As it is probably unrealistic to anticipate well-designed randomised controlled trials addressing the impact of cross-sectional imaging on patient outcomes, this type of laboratory study may be the best research design available. It is interesting that there is some evidence for the effect of case difficulty on the impact of cross-sectional imaging in a previous clinical study, in which the eligibility criteria excluded complex cases[32] and cross-sectional imaging had almost no impact on treatment planning.

It appears that cross-sectional imaging improves the confidence of surgeons when planning implant treatment[30,36,39]. Shelley et al[41] demonstrated that the availability of CBCT images leads to a perception of higher surgical difficulty and this can perhaps be considered as an aspect of surgical confidence. Nevertheless, surgical confidence is only acceptable as evidence for the need for cross-sectional imaging, if it translates into patient benefits, whether those are indirect, such as through shorter operating times, or by direct improvement in patient outcomes. Evidence of this type from randomised controlled trials at Level 5 of Fryback and Thornbury's hierarchy does not exist however.

Five studies included the necessity for surgical bone grafting as an outcome measure[33,35,36,40,41]. None of the studies unequivocally demonstrated a difference after cross-sectional imaging was available. Whilst the study of Fortin et al[35] suggested that the availability of CBCT imaging reduced the need for sinus augmentation surgery, the three assessors in the 'before' part of the study were different from the single assessor in the 'after' part of the study. The difference in the two parts of the study, therefore, may have represented a difference in practice between the assessors rather than the effect of the availability of different image types. It is notable that Baciut et al[36] found almost perfect concordance between treatment choices (prediction of graft volume, prediction of complications, assessment of sinus morphology, choice of treatment or of timing of treatment), made using panoramic radiography and CBCT but, paradoxically and inexplicably, concluded that cross-sectional imaging "should be recommended in all cases for sinus lift". The findings of Guerrero et al[40] suggest that availability of CBCT increases the sensitivity of presurgical assessment of the necessity for bone grafting or the prediction of several potential complications (fenestrations, dehiscence, membrane perforations and wrong angulations), although by combining all of these in the statistical analysis, it is impossible to determine whether all factors were equally affected.

Only one study considered the perception of image quality[39] and found, perhaps unsurprisingly, that CBCT images were perceived as better quality than panoramic images alone. Nevertheless, there is a level of image quality above which the image becomes clinically useful and, it can be presumed, there is a leve of image quality above which no additional clinical usefulness is obtained. Difference in image quality, therefore, does not necessarily lead to a difference in clinical usefulness or a benefit to the patient. This cannot, therefore, be considered as evidence supporting the need for cross-sectional imaging.

Other treatments for the missing single tooth

Although this systematic review was focused on the issue of cross-sectional imaging in the context of

Table 5 Scope and limitations of the radiographic imaging techniques available to clinicians as part of the preoperative evaluation of single missing teeth, including diagnosis of pathosis within the edentulous space and of adjacent teeth. Usefulness is indicated by +, ++ or +++, according to potential value. No useful role is shown by -.

	Intraoral radiograph	Panoramic radiograph	Lateral radio-graph†	Conventional tomogram	CBCT*	CT*
Measurements:						
Mesio-distal	++	++	-	-	+++	+++
Supero-inferior	++	++	-/+	++	+++	+++
Bucco-lingual	-	-	-/+	++	+++	+++
Bone external morphology	-	-	+	+	+++	+++
Bone internal morphology	++	+	-	-	+/+++	+/++
Bone density	+	+	-	-	-/++	+++
Anatomical structures and boundaries	++	++	-	+	++/+++	+/+++
Tooth-related pathosis:						
Dental caries	++	+	-	-	-	-
Periodontal bone levels	++	+	-	-	++/+++	-/+
Periapical inflammation	++	+	-	-	++/+++	-/+
Root fracture	++	-	-	-	++	-

* Variation in the efficacy for the CBCT reflects wide variation between image quality of different equipment and according to exposures used.

†This includes both the lateral cephalogram and the transymphyseal radiograph.

treatment using an implant, pre-treatment radiological assessment of single missing teeth goes beyond this method of treatment. There are four principal treatments for missing single teeth apart from an implant-supported crown: mucosal-supported denture, tooth-supported denture, adhesive bridge and conventional bridge. There is a variety of radiological examinations available to the clinician. This breadth of treatment options means that most of the imaging options available to clinicians can have a role to play, either alone or in combination. It is beyond the remit of this paper to review comprehensively the scope and limitations of all the imaging techniques which can be found in contemporary textbooks and some review publications[7,17], but Table 5 gives a summary of the diagnostic capabilities of the principal radiograph imaging methods. It should be noted that the scope of all imaging methods rely on a meticulous technique. For CBCT in particular, there is also wide variation in its capabilities, which reflect variations in technical efficacy[43,44].

One factor of particular relevance to the single missing tooth situation and both CBCT and CT is artefact related to metallic objects[45]. This phenomenon results in streaks in the plane of the radiograph beam, which radiate from the object, leading to loss of anatomical information. This may be particularly evident where two metallic objects are fairly close together. If the teeth on either side of a single missing tooth space contain root fillings or metal posts, this can significantly reduce the diagnostic value of the CBCT/CT examination. Metal artefact reduction algorithms are of limited or no value because they mask the artefact rather than restore missing anatomical information[46-48]; this phenomenon is not seen with conventional tomograms.

Radiation aspects

The justification process for selecting radiological techniques requires consideration of the likely benefits of radiograph examination against the risks. In diagnostic radiology, the risks are of somatic stochastic effects, i.e. deleterious effects on the irradiated individual that have a specific probability of occurring. The only somatic stochastic risk is of cancer. Tissue effects (formerly deterministic effects) have threshold doses that would normally be impossible to exceed by dental imaging, therefore can be reasonably ignored. As described in a recent review[49], cancers of various types have been associated with oro-facial radiology, including those of the salivary

Table 6 Effective doses for dental radiological examinations. The data represent a summary of review publications[3,17,49-51]. All doses in mSv. The field of view subdivisions for CBCT vary according to authors' definitions, but are broadly equivalent.

Radiological examination	Effective dose (mSv)	References
Intraoral radiograph	< 0.002	3
	< 0.002	17
	0.003-0.022	49
Panoramic radiograph	0.003-0.024	3
	0.003-0.024	17
	0.003-0.038	49
Lateral cephalogram	< 0.006	3
	< 0.006	17
	0.002-0.014	49
Conventional tomogram	0.047-0.088	17
CBCT (dentoalveolar)	0.011-0.674* (median 0.061)	3
	0.019-0.674*	17
	0.011-0.214	49
	0.005-0.652 (mean adult 0.084)	50
	0.010-0.197 (median 0.028)	51
CBCT medium FOV	0.018-0.674	49
	0.009-0.560 (mean adult 0.177)	50
	0.004-0.674 (median 0.070)	51
CBCT (craniofacial)	0.030-1.073 (median 0.087)	3
	0.030-1.073	17
	0.030-1.025	49
	0.046-1.073 (mean adult 0.212)	50
	0.009-1.073 (median 0.114)	51
CT	0.280 -1.410	3
	0.280 -1.410	17
	0.250-1.410	49

* Harris et al[17]: the dentoalveolar field of view encompassed the medium field of view.

glands, thyroid and brain, as well as the leukaemias. Risk of cancer related to exposure to radiographs is age-dependent, being two to three times higher for children than adults and steadily falling with advancing years. The risk of fatal cancer is estimated at 5% per sievert[1]. In other words, if one million people receive 1mSv of an effective dose, 50 might develop a fatal cancer.

An effective dose is the tissue-weighted sum of the equivalent doses in all specified tissues and organs of the body. It is widely used because it takes account of the specific organs and tissues through which the radiation passes and is directly related to cancer risk. Effective doses associated with dental radiographic examinations have been reviewed on several occasions, both specifically or as part of guideline documents, although recent reviews have tended to focus on CBCT alone[3,17,49-51]. Table 6 provides a summary of data from these publications. Wide ranges are seen for most radiographic examinations, as the effective dose is influenced by so many variables. For example, while a localised radiographic examination, for example a periapical radiograph, may use a fixed set of exposure factors, the resultant effective dose will differ according to anatomical location in the jaws because of the different tissues irradiated. Thus it is essential to recognise that there is no single dose for a particular radiographic examination. A comparison such as "a CBCT scan is equivalent in dose to four panoramic radiographs" is nonsense unless the precise details of the equipment are known and dose measurements have been made. Effective doses in children are not necessarily the same as adult doses for the same examination; indeed, they may be higher than for adults even if lower exposure factors are used because of the different volume of the patient that is irradiated and the relative differences in the position of some organs, for example the thyroid gland[17,50,52].

In the context of preoperative radiological management of missing single teeth, the higher dose levels of CT have meant that, understandably, clinicians may have been reluctant to use it. Conventional tomograms, however, offer a relatively low dose and are suitable to single implant cases. CBCT systems vary considerably, but some offer limited fields of view e.g. 4 or 5 cm in height and diameter. Generally, a smaller CBCT field of view is associated with a smaller dose than larger fields[3], therefore for practitioners performing single implants it is easier to justify CBCT than it is to justify CT[3]. An effort should always be made to reduce the dose associated with the radiological examination to a level that is as low as reasonably practicable and diagnostically acceptable. All available imaging modalities must have the exposure factors (tube current-exposure time product, mAs and operating potential kV) appropriately set. Additionally, other factors are important in terms of dose reduction and these are set out in Table 7.

The need for correct setting of mAs and kV are common during optimisation of all radiograph systems. It is important to be aware that, for digital imaging systems, adequate image quality can be achieved over a wide exposure range. Manufacturers often advise higher exposure factors than are necessary because this flatters the image quality of their equipment. For CBCT, there is substantial evidence that exposure factors can be reduced from the manufacturers' recommended values for a range of equipment, in the context of implant planning[53-58]. Optimisation of exposure factors is best performed with the assistance of a medical physics expert rather than a trial and error approach for turning down the exposures. Due to the generally higher doses used with CBCT than conventional imaging, optimisation is of particular importance[3] and both Harris et al[17] and Hidalgo Rivas et al[59] have described low-dose protocols for CBCT, the former in the context of implant planning.

Table 7 The main factors, other than exposure factors (tube current-exposure time product, mAs and operating potential, kV), that favour a lower radiation dose in dental radiological examinations.

Radiological examination	Factors favouring a lower dose
Intraoral radiograph	Fast film (F-speed) or digital detector Rectangular collimation Paralleling technique
Panoramic radiograph	Fast film/screen combination or digital system Field size limitation
Lateral cephalogram	Fast film/screen combination or digital system Field size limitation
Conventional tomogram	Fast film/screen combination or digital system As few 'cuts' as possible
CBCT	Field size limitation Largest voxel size consistent with clinical needs
CT	Request 'low dose protocol' (e.g. mAs < 100) Slice thickness 1 mm Pitch 1 to 1.5 Suggested window width: 1250; level 250

Financial costs

Although the justification process is one of balancing radiation-associated risk against benefit, in the real world, financial costs also have an influence. In a public healthcare system with finite resources, increased expenditure on a new diagnostic or therapeutic technique will leave less resource for others. In a purely private system, patients or insurance companies may pay for the intervention recommended by the clinician, but will be expecting some clinical benefit from that payment.

Economic evaluation of diagnostic methods in oral health care, including imaging techniques, has an extremely limited literature, as shown in a recent systematic review by Christell et al[60]. They identified 12 studies, of which only two are relevant to the current review. To these can be added one subsequently published study[61].

Scaf et al 62 compared radiation doses and financial costs of film-based tomography and CT scanning. The economic component in this US-based study was rudimentary and consisted of a simple survey of examination costs; this revealed that CT was the more expensive option. As film-based tomography is increasingly of historical interest and the study is 20 years old, there is nothing of current value in this study. Furthermore, as Christell et al[60] point out, simply measuring expenditures is not a substitute for well conducted original costing, that involves measuring quantities of resources required to deliver the intervention. Two studies[61,63] are of interest in that they included cost analyses. Christell et al[63] compared 'conventional' radiographic examination (panoramic and intraoral radiographs) with additional CBCT examination in different healthcare systems in three countries, in the context of evaluation of ectopic canines. The other study[61] was a randomised controlled trial of CBCT in the management of mandibular third molars and included a cost analysis. Both studies showed that costs were higher when CBCT was added to the imaging, although Christell et al[63] found significant variations between countries in terms of costs, emphasising that cost analyses are not easily transferable.

Cost analysis is only part of a complete economic evaluation. The costs have to be considered against the benefits. Christell et al[60] point out that benefits must be considered against the hierarchy of diagnostic efficacy by Fryback and Thornbury[2]. The highest level of assessment considers Level 5 (outcome efficacy) using a randomised-controlled trial design with concurrent Level 6 (economic evaluation). Petersen et al[61] found that cross-sectional imaging in the form of CBCT did not change the resources used in relation to mandibular third molar surgery. There was, unfortunately, an absence of literature of this quality, in the context of the current systematic review related to implants.

Selection criteria for preoperative radiological evaluation

A patient requiring treatment for a missing single tooth would do so as part of comprehensive oral care, with the possible exception of treatment using an implant where onward referral to a specialist is made. Selection criteria for oral radiography for a new adult patient have been described in various guidelines[5,6,7], all of which have undergone multiple editions over the years. All agree that no radiographic examination is indicated unless a full history and clinical examination has been taken and that posterior bitewing radiography and selected periapical radiographs are appropriate for dentate or partially dentate patients. In the context of the current review, examination of these guideline documents did not show any specific guidance on radiographs when planning partial dentures. There was, however, agreement that periapical radiography of potential abutment teeth was indicated when a bridge is planned.

When a mucosal-supported denture is planned for restoration of a missing single tooth, there is no apparent justification to radiograph the edentulous space in the absence of clinical signs or symptoms. While this seems obvious, it should be noted that the ADA guidelines[6] give an equivocal message, saying that "prescription of radiographs is appropriate as part of the initial assessment of edentulous areas for possible prosthetic treatment", but do not explain why this should be. They conclude, however, with this recommendation: "an individualized radiographic examination, based on clinical signs, symptoms, and treatment plan is recommended", the wording of which suggests that absence of signs and symptoms would preclude radiography.

Where a tooth-supported denture is planned, the ADA guidelines are unequivocal in recommending intraoral radiography of abutments, whereas other guidelines do not suggest this. The rationale for radiography of denture abutments is presumably the same as that for potential bridge abutments. The recommendation to radiograph potential bridge abutment teeth, regardless of clinical signs or symptoms of disease, appears to be based on the evidence of increased incidence of periapical inflammatory pathosis in heavily restored, crowned and endodontically treated teeth[64-72]. There is also evidence that greater restoration depth is associated with a higher frequency of periapical inflammatory disease[64], as is inadequacy of the restoration[66-70]. In one study, 19% of non-root filled crowned teeth showed evidence of periapical periodontitis[65]. If a potential bridge abutment tooth has been endodontically treated, has a large restoration or the restoration is inadequate on clinical examination or on bitewing radiography, then a periapical radiograph can be justified based on the evidence. In a situation of an unrestored, clinically healthy, potential bridge abutment tooth, there is no apparent evidence to justify a radiographic examination. It should be noted that panoramic radiography has inferior diagnostic accuracy efficacy to periapical radiography[73].

The role of cross-sectional imaging, in particular CBCT, for non-implant related purposes, remains a developing field of research. However, several guidelines exist, which was reviewed by Horner et al[25], and one other has subsequently appeared[20]. While none has specifically focused on preoperative evaluation of missing single teeth, there is broad agreement that CBCT should be used in situations where conventional radiography fails to answer the diagnostic question; in other words, it should be seen as a second line of diagnosis. Table 8 provides a summary of guidelines for preoperative radiological evaluation of missing single teeth when non-implant treatment is planned.

Where an implant treatment is chosen for a single tooth space, the clinician is seeking information on bone dimensions, shape, density, the positions of relevant important anatomy and the presence of pathosis at and immediately adjacent to the proposed site of implant placement. Clinical examination followed by conventional radiographic examination (intraoral and, in many cases, panoramic radiographs) may be adequate for these needs. The use of a reference object of known dimensions, such as a ball bearing, in the plane of the dental arch will assist in measurement[15]. The decision to supplement conventional radiography with cross-sectional imaging should be made after conventional radiography has been evaluated. This may avoid unnecessary cross-sectional imaging, avoiding the associated radiation dose and financial cost. As the current sys-

Table 8 Suggested guidelines for preoperative radiological evaluation of missing single teeth (non-implant-based treatments). This assumes that normal selection criteria[5,6,7] for dental radiography of a new patient have been followed.

<table>
<tr><th>Treatment under consideration</th><th>Recommended imaging</th><th>Cross-sectional imaging</th></tr>
<tr><td>Mucosal-supported denture</td><td>None</td><td rowspan="4">Consider small field-of-view* CBCT:
If radiographs give a negative finding when there are contradictory positive clinical signs and symptoms.
In cases where radiographs provide information which is equivocal or inadequate for planning treatment,
In cases where cross-sectional imaging is likely to alter the management or prognosis of the tooth</td></tr>
<tr><td>Tooth-supported denture</td><td>None may be needed
If there are clinical concerns, periapical radiographs of abutment teeth</td></tr>
<tr><td>Resin-retained bridge</td><td>None may be needed
If there are clinical concerns, periapical radiograph of abutment teeth.</td></tr>
<tr><td>Conventional bridge</td><td>Periapical radiographs of abutment teeth</td></tr>
</table>

* small field of view CBCT implies a diameter < 5cm

tematic review failed to identify any clear selection criteria for cross-sectional imaging, existing opinion/consensus-based guidelines recommending selected use should be considered.

As described in the introduction, available guidelines fall into two categories, those recommending the use of cross-sectional imaging for all proposed implant sites[8-11] and those recommending selected use[3,7,12-20]. Those favouring a selected approach are in broad agreement, regarding the situations in which cross-sectional imaging may be indicated (Table 9), although it should be noted that some of these situations would not be satisfactorily imaged using conventional tomography and require the use of either CBCT or CT.

The position statements of the AAOMR and the FGDP(UK) selection criteria in dental radiography mention the experience of the implant practitioner as a factor in image selection and, the FGDP(UK) document states that three-dimensional imaging increases surgical confidence for less experienced operators[7,11]. Studies[30,36,39] confirm increased surgical confidence when three- dimensional imaging is available and in one questionnaire study, inexperienced operators were more likely to prescribe three- dimensional images[75]. It would appear to be the common sense position that some inexperienced operators may benefit from increased surgical confidence when three-dimensional imaging is available preoperatively. Nonetheless, evidence that increased surgical confidence leads to an improvement in patient outcome is lacking.

Postoperative radiological evaluation

It was not the remit of this review to consider choices relating to post-implant review imaging, therefore only brief comments are included here. When selecting the appropriate imaging modality for review, most guideline documents emphasise that under normal circumstances the use of cross-sectional imaging should not be the standard[11,12,20]. In the case of CBCT or multislice CT, artefact immediately around implants may mimic failure of osseointegration and also obscure bony detail more distant to the implant[20]. Furthermore, very thin bone, such as that which may be present buccally over an implant surface, may not be visible, although this will depend on the resolution of the system and any artefact due to patient movement, amongst other factors. Cross-sectional imaging after implant placement may be indicated when there are complications, such as suspected perforations of the bony cortices, implant mobility, suspected involvement of neurovascular structures, osteomyelitis, maxillary sinus complications[11,12,15,16,17] or complications after bone grafting[15,16]. Under normal circumstances, intraoral radiography, performed using meticulous technique with film/sensor/imaging plate holders and a beam-aiming device are appropriate[7,11]. For a single tooth implant, positioning of an intraoral radiograph should be straightforward and a panoramic radiograph, with its inherently inferior detail, should not normally be used.

In terms of the frequency of review imaging, guideline documents frequently give no advice. One guideline document states that "postoperative

Table 9 Situations in which cross-sectional imaging may be of value when planning implants, according to current guideline documents which provide detailed criteria. As different terminology is used in different guidelines, the authors have grouped and rephrased these appropriately. Indications not relevant to single tooth situations (e.g. zygomatic implants) have been omitted.

Situations in which cross-sectional imaging may be of value when planning implants	References
When clinical and conventional radiographic examination have failed to demonstrate anatomical boundaries/ structures adequately	7,12,15,17,20
History and clinical examination with a significant deviation from standard anatomy	12,15
In clinical borderline situations where there appears to be limited bone height and/or bone width available for successful implant treatment	12,16,17,20
Highly aesthetic zone	16
When computer-aided implant planning is to be used	7,15,16,17
When surgical navigation is to be used	15,16
When the maxillary sinus has a possible influence on implant restoration in the posterior maxilla (e.g. sinusitis)	7,15,17
Pre-bone grafting, including sinus augmentation and bone defects* Post-bone grafting*	12,16,17, 20
History of pathosis or suspected pathosis of the jaws requiring further clarification after conventional radiography	15,16
Cases in the A or C categories of the SAC (straightforward, advanced and complex) classification+ "can generally be regarded as identical with the recommendation for the use of CBCT in the preoperative assessment".	20
If there is a considerable risk of harm from the surgical intervention when performed following only plain film imaging	20

* Post-bone grafting only mentioned as the standard for all cases by Benavides et al[16], while AWMF[15] state cases of dubious success or complication after augmentation.

+ Dawson and Chen[74]

review protocols appear to be the subjective opinion of authors"[7]. This document advises that a radiograph is appropriate at baseline and after 12 months, but that an ongoing review interval of 1, 3 and up to 5 years is suggested. It seems likely that suggestions on appropriate radiographic review intervals have emerged secondary to guidance on the periodicity of clinical review intervals. One guideline document suggests that clinical recall appointments are recommended within 6 months of restoration and at least annually thereafter, without explicit recommendation that this frequency also applies to radiographs, yet it also suggests that radiographic appearance is one consideration in evaluating implants at recall[22]. No evidence is cited to support these recommendations. Clearly, however, clinical signs of pathosis, such as increased probing depth, bleeding, exudate and mobility are criteria to justify a radiographic examination.

A widely used criterion for success of an implant is that radiographic marginal bone loss at surfaces facing the implant should be less than 1.0 mm in the first year of function and that subsequent annual bone loss should not exceed 0.2 mm[76]. It is notable that publications describing bone loss after implant placement use submillimetre measurements. For example, a recent systematic review and meta-analysis reported that mean marginal peri-implant bone loss around single-implant prostheses was 0.58 mm (95% CI: 0.37 to 0.80 mm)[77]. It is important to recognise that submillimetre dimensions are the product of averaging multiple measurements and that the latter are very unlikely to have these levels of precision and reliability when applied to individual patients and implants. Although some research studies, using meticulous radiographic and measurement methods, report intra- and inter-observer variability in measurements far lower than 1 mm[78], others have shown relatively high measurement error[79] meaning 'real world' accuracy and precision in a typical dental office will be less. Thus, clinicians should be cautious in interpreting the clinical significance of submillimetre measurements of marginal bone from radiographs.

The implications in the difficulty of obtaining precise measurements of bone levels on radiographs, may be that it is pointless to take review radiographs at very frequent intervals in everyday clinical practice, in the absence of clinical signs or symptoms and that a more logical approach could be adopted, such as:

1. Baseline radiograph at the fitting of the prosthesis.
2. Radiograph after 1 year. If bone loss is < 1 mm, then re-radiograph after 5 years. The rationale for 5 years is that if there is bone loss of 0.2 mm per year, it would be measurable with acceptable precision. If there is evidence of stabilisation of bone levels at this 5 year point, future radiographic examination would be indicated only if there were clinical signs, symptoms or other specific concerns.
3. If bone loss at the 1 year point is > 1 mm, then radiograph again after a further 12 months (i.e. at the 2 year point). If the 2 year radiograph shows further measurable bone loss then consider ongoing annual radiographic examination until there is evidence of stabilisation of bone loss to acceptable levels.

Of course, a radiograph might be taken at any time point if there is a clinically evident problem.

Conclusions

The systematic review failed to provide convincing evidence to answer the question: does the use of additional cross-sectional imaging have any impact on diagnostic thinking, treatment planning or outcome compared with conventional imaging alone, in the preoperative evaluation of single missing teeth for implant treatment? All included studies had methodological limitations and results were sometimes contradictory. It can be suggested in cases that are identified by an experienced clinician as being straightforward on clinical examination and on the conventional radiographs, there may be no need for cross-sectional imaging. This is in line with a previous recommendation[12]. Consequently, guidelines based on a consensus of experts suggesting selection criteria for cross-sectional imaging are of considerable value.

When all potential treatments for missing single teeth are considered, imaging choices are not based on robust research evidence in the form of randomised controlled trials or economic evaluations. For non-implant treatments, there is broad agreement amongst guidelines, about the need for intraoral periapical radiography of potential bridge abutment teeth, mainly based upon evidence from radiographic clinical surveys. An exception to this may be the clinically healthy, unrestored abutment tooth.

Overall, this review has highlighted that, in terms of preoperative radiological evaluation of missing single teeth, much of what we do lacks a solid basis in the research evidence. It is therefore appropriate for the surgeon to use imaging wisely according to the individual patient's needs, taking into account the history and findings on the clinical examination, radiation dose, financial costs and after reflecting on personal surgical skill and experience.

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