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EDITORIAL

# Outcome of endodontic treatment – the elephant in the room

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Outcome data from well designed and conducted clinical trials are essential to evaluate the safety and effectiveness of endodontic procedures from vital pulp therapy to microsurgical re-treatment. Such information allows clinicians to discuss risks, success rates, prognostic factors and alternative management options with patients, and only with such information can patients make properly informed decisions about their care.

It is not uncommon for endodontic disease to be clinically asymptomatic (Kirkevang & Hørsted-Bindlev 2002, Huumonen & Ørstavik 2002), and radiological assessment is therefore essential to objectively determine its presence for both untreated and previously treated teeth (Patel *et al.* 2012). Dentists have traditionally relied on a combination of clinical evaluation and periapical radiographs as their reference standard to evaluate the presence or absence of endodontic disease. Apical periodontitis usually manifests radiographically as a periapical radiolucency, due to reduced mineral density of the affected bone in response to localized inflammation. In most circumstances, this is promoted by microbial infection within the root canal system (Bender 1982, Patel *et al.* 2012). The absence of a radiolucency indicates the absence of apical periodontitis, and by inference, the absence of root canal infection; a key determinant of treatment success (European Society of Endodontology 2006).

The advent of 3D imaging systems such as cone-beam computed tomography (CBCT) has complicated matters by identifying more periapical radiolucencies than traditional methods, though uncertainty remains about the healing dynamics of lesions identified and monitored by CBCT, and their histological status at intervals after treatment.

Increasingly, tooth survival has become established as an alternative outcome measure. Survival data identify teeth that are lost due to symptoms or risks that are unacceptable to patients, but accepts the presence of teeth that may have signs, symptoms and radiographic features of apical periodontitis, but which are judged as acceptable by patients (Friedman *et al.* 2003, Doyle *et al.* 2006).

This gradual shift in focus begs the question whether asymptomatic apical periodontitis is an important disease, and whether persistent radiolucencies identified on CBCT images are associated with significant risks of local flare-up or systemic consequences, and if so, whether particular patient groups are at risk. These uncertainties become increasingly relevant as populations age with increasing frailty, vulnerability and co-morbidities caused by medical conditions, medical treatment and the effects of ageing.

The aim of this editorial is to appraise the use of periapical radiographs and CBCT in determining endodontic treatment outcomes and highlight a number of important questions (elephants in the room) that must be addressed if we are to provide more complete data to inform clinical decision-making.

## How do we objectively assess endodontic treatment outcome?

For more than 100 years, periapical radiographs have been the standard method to detect the presence or confirm the absence of apical periodontitis, with numerous studies showing high levels of endodontic treatment success (de Chevigny *et al.* 2008, Ng *et al.*

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2011, Patel *et al.* 2012). Despite the simplicity and objectivity of traditional radiographic methods, and the acquisition of readily quantified data, the limitations of 2D images are well recognized (Bender & Seltzer 1961, Brynolf 1967, Kanagasingam *et al.* 2017a). Periapical radiolucencies may be missed and/or under-estimated due to the superimposition of overlying cortical bone and/or geometric distortion. Despite this, not one outcome study using periapical radiographs has acknowledged their limited sensitivity or questioned the accuracy of the outcome assessment (Wu *et al.* 2009).

Over the last two decades, the use of small field of view (FOV) CBCT has steadily increased in endodontics (Setzer *et al.* 2017). Clinical studies have shown 11–39% and 20–34% increased detection of periapical radiolucencies with CBCT compared to periapical radiographs in teeth treatment planned for primary and secondary endodontic treatment respectively (Table 1). Live animal and human cadaver studies have confirmed the enhanced accuracy of CBCT in detecting periapical radiolucencies that may not be visible on periapical radiographs (Paula-Silva *et al.* 2009, Kanagasingam *et al.* 2017b, Kruse *et al.* 2019). The recent observation from a human cadaver study that approximately 20% of roots with canal fillings and histologically 'healthy' periapical tissues may have been judged as diseased on CBCT (Kruse *et al.* 2019) provides an incomplete picture as the original periapical status of the teeth examined was unknown. This study does, however, point to the potential dangers of over-treating previously root filled teeth that have radiolucencies identified on CBCT images. Lesions may simply take longer to resolve completely when monitored by 3D imaging techniques.

In an outcome study conducted 12 months after primary root canal treatment, Patel *et al.* (2012) reported that 87% of periapical radiolucencies had *healed* (i.e. complete resolution) on PR, compared with 62.5% on CBCT images. Ninety-five percent of periapical radiolucencies were judged to be *healing* (i.e. periapical radiolucencies reducing in size) on periapical radiographs, compared with 84.7% on CBCT images. For teeth with no preoperative apical periodontitis, CBCT images revealed periapical radiolucencies in 17.6% of cases, compared with just 1.3% on periapical radiographs. The difference was highly significant. However, for teeth with preoperative apical periodontitis, the difference was not statistically significant, with 13.9% failures observed on CBCT images and 10.4% on periapical radiographs.

Using the same methodology to assess the 12-month outcome of root canal re-treatment, 93% of periapical radiolucencies were judged to be *healing* on periapical radiographs, compared with 77% on CBCT. *Healed* rates were 78% with periapical radiographs and 61% with CBCT (Davies *et al.* 2016). Though the recall intervals were short in both studies, there was a higher detection of radiographic signs of post-endodontic disease in molar teeth with CBCT. It is again uncertain how outcomes would change following longer-term recall.

**Table 1** Clinical studies comparing the detection of periapical periapical radiolucencies between CBCT and periapical radiographs in untreated and endodontically treated teeth. CBCT images revealed a greater prevalence of periapical radiolucencies when compared to periapical radiographs (11–39%) (from Patel *et al.* 2019b)

| | CBCT > PR (%) | Teeth |
|---|---|---|
| Primary endodontic treatment | | |
| Estrela *et al.* (2008) | 39 | 83 (untreated) |
| Patel *et al.* (2012) | 28 | 151 (untreated) |
| Abella *et al.* (2012) | 11 | 128 (irreversible) |
| Abella *et al.* (2014) | 19 | 161 (non-vital) |
| Secondary endodontic treatment | | |
| Lofthag-Hansen *et al.* (2007) | 20 | 46 (re-rct) |
| Estrela *et al.* (2008) | 28 | 1425 (re-rct) |
| Low *et al.* (2008) | 34 | 74 (re-rct) |
| Bornstein *et al.* (2011) | 26 | 38 (re-rct) |
| Cheung *et al.* (2013) | 30 | 60 (re-rct) |
| Venskutonis *et al.* (2014) | 25 | 35 (re-rct) |
| Davies *et al.* (2015) | 30 | 100 (re-rct) |
| Uraba *et al.* (2016) | 21 | 178 (re-rct) |
| | **CBCT > radiographs (%)** | **Teeth** |
| Primary + Secondary endodontic treatment | | |
| Weissman *et al.* (2015) | 22 | 67 (untreated + re-rct) |

Recently, the 12-month data from three primary and secondary root canal treatment outcome studies involving 354 teeth, identified signs of healing in 90% of anterior, premolar and molar teeth on periapical radiographs (Al Nuaimi *et al.* 2018). These figures are comparable to previous studies (de Chevigny *et al.* 2008, Ng *et al.* 2011). For anterior and premolar teeth, there was almost perfect agreement on lesion detection with CBCT and periapical radiographs (90%), but only 75% of molars were judged to have healed or healing lesions on CBCT (Al Nuaimi *et al.* 2018). This difference in outcome was primarily associated with the larger number of pre-treatment (baseline) radiolucencies detected with CBCT (188 with periapical radiographs vs 264 with CBCT in a cohort of 346 teeth).

The increased number of radiolucencies associated with molar teeth observed by CBCT may indicate delayed healing compared to observations on periapical radiographs. However, when data from two outcome studies on primary and secondary root canal treatment in posterior teeth are pooled (Patel *et al.* 2012, Al Nuaimi *et al.* 2017, 2018), there is a highly significant difference (Fisher's exact test two-tailed $P = 0.0063$) between the number of new, enlarging and unchanged radiolucencies detected with CBCT images compared to periapical radiographs, indicating increased radiographic signs of post-endodontic disease detected by CBCT (Table 2), at least at 12-month follow-up. These differences in detection rates between periapical radiographs and CBCT in the posterior region are largely attributed to anatomical noise resulting in periapical radiolucencies being hidden from detection on periapical radiographs. What remains uncertain once again is the progress of such lesions over longer-term recall intervals.

Based on current evidence, periapical radiographs combined with clinical evaluation of signs and symptoms is appropriate for routine outcome assessment in anterior and premolar regions, both in clinical practice and in clinical trials. However, given the obvious lack of sensitivity of periapical radiographs in detecting radiolucencies in the molar region, it may be questioned whether researchers should still advocate their use as the gold standard method of assessing treatment outcomes in clinical trials.

## Should CBCT be used routinely to diagnose and assess the outcome of endodontic treatment in molar teeth?

At the present time, small FOV CBCT cannot be recommended for the routine assessment of endodontic treatment outcomes. However, in specific situations it may be relevant, particularly in the management of posterior teeth, for example where apical periodontitis is suspected but not revealed on periapical radiographs.

In vital pulp therapy, Hashem *et al.* (2015) examined molar teeth with reversible pulpitis by periapical radiographs and CBCT pre-treatment and 12 months post-treatment. Diagnosis and treatment planning were determined solely on the basis of clinical examination and assessment using periapical radiographs, and clinicians gained access to the pre-treatment CBCT only when they assessed the outcome of treatment. At 12-month follow-up, use of periapical radiographs identified 90% of cases was successful, compared to 65% with CBCT, judged by the presence or absence of a lucency. For teeth with preoperative apical periodontitis identified by CBCT, 37% were successful at 12 months, compared with 84% where no lesion had been identified by CBCT. The exclusion of teeth with such preoperative CBCT-detected radiolucencies from a successive clinical trial on deep caries management was associated with improved success rates (Ali *et al.* 2018). These findings suggest that CBCT may be helpful for the assessment of teeth being considered for vital pulp therapy to detect potential 'hidden' radiolucencies which may not be detected on periapical radiographs and which may reflect a less advantageous pulpal status.

There is growing evidence that CBCT imaging improves diagnostic accuracy, decision-making and/or change/enhances treatment planning (Ee *et al.* 2014, Davies *et al.* 2016, Rodríguez *et al.* 2017a,b). A recent study has also revealed that the additional information gained from CBCT images reduced the stress levels of a cohort of clinicians treating molar teeth and also improved the radiographic quality of root fillings; a factor that has long been associated with treatment outcome (Patel *et al.* 2019a). However, further research is needed to assess whether such observations are true for all clinicians, especially those with no previous experience of working with CBCT. Uncertainties also remain on the impact of preoperative CBCT scans on improving clinical safety and efficacy, and how these factors impact on

**Table 2** Pooled data of posterior teeth from Patel *et al.* (2012) and Al Nuaimi *et al.* (2017)

| | New radiolucencies<br>Enlarged radiolucencies<br>Unchanged radiolucencies | Resolved radiolucencies<br>Reduced radiolucencies<br>No radiolucencies before treatment and at recall |
|---|---|---|
| Periapical radiographs | 18 | 207 |
| CBCT | 38 | 187 |

The increased failure rate in the CBCT assessment of posterior teeth is caused by the larger number of new, unchanged and enlarged radiolucencies detected on CBCT images.

treatment outcomes in terms of periapical health, tooth survival, reduced disease risk and patient satisfaction.

The benefits of CBCT must always be balanced with concerns for radiation protection and this may be enhanced by guidelines to minimize dose (European Society of Endodontology 2019). The effective dose of small FOV (<5cm) CBCT scans can be 3–20 times higher when compared to periapical radiographs depending on the scanner used, exposure parameters and the resolution setting. The quality of reconstructed CBCT images varies considerably between small FOV scanners, which in turn has an impact on the diagnostic accuracy of detecting apical periodontitis (Patel *et al.* 2019b). Radiation protection agencies and/or maxillofacial radiology societies should be encouraged to study the impact of image quality and artefacts on diagnostic accuracy and ultimately provide clear and evidence-based guidelines on dose reduction protocols and image quality for small FOV CBCT scans.

## Classification of outcome

The European Society of Endodontology Quality Guidelines (European Society of Endodontology 2006) emphasize the role of periapical radiographic healing in determining treatment success. When a periapical radiolucency has diminished but not completely resolved within 4 years, the outcome is considered ‘unfavourable’, requiring discussion of further treatment. Such judgements are based on the interpretation of periapical radiographs. The healing dynamics of periapical radiolucencies monitored by CBCT are not addressed, and the likely presence of more persistent periapical radiolucencies at 4 years compared with those identified on periapical radiographs begs the question whether 4 years is an appropriate cut-off for monitoring with CBCT or if longer periods of monitoring are indicated before considering further intervention.

Although the accuracy of CBCT in detecting apical periodontitis associated with endodontically treated and non-endodontically treated teeth with moderate to severe inflammation is around 90%, the accuracy for detecting mildly inflamed or healthy periapical tissues is lower in root filled teeth (70-80%) (Kanagasingam *et al.* 2017b, Kruse *et al.* 2019). The pathological nature of such radiolucencies and the risks they may present to healthy and vulnerable individuals remains uncertain, with only a limited number of cadaveric studies correlating radiolucencies identified by CBCT with histopathological findings. Periapical radiolucencies that persist but are healing slowly may reasonably be defined as ‘healing’ rather ‘unfavourable’ as defined by current guidelines when judged 4 years after treatment (European Society of Endodontology 2006).

Definitions of outcome are also relevant to patient decision-making, notably between endodontic treatment and implant replacement, where survival data reveal that restored endodontically treated teeth have comparable survival rates to restored implants, and where both modalities of treatment may be associated with varying degrees of periapical or peri-implant inflammation (Doyle *et al.* 2006, Ng, *et al.* 2010). The true local and systemic risks of apical periodontitis and peri-implantitis are yet to be fully elucidated.

As populations age with increasingly complex comorbidities and as the effectiveness of antibiotic treatment becomes less certain, the systemic risks of acute and chronic dental infections must not be dismissed. Case reports identify risks of sepsis associated with infected teeth in susceptible individuals (Newman 1996, Olsen & van Winkelhoff 2014, Oriol *et al.* 2015), and work continues on other systemic associations (Aminoshariae *et al.* 2017), including the elevation of inflammatory mediators associated with endodontic infections and endothelial dysfunction (Cotti *et al.* 2011). Potential patient vulnerability is illustrated by the greatly increasing numbers of patients undergoing joint replacement (National Joint registry 15th Annual Report 2018), organ transplantation (Organ Donation & transplantation activity report 2018/2019) and immunosuppressive treatments for neoplastic disease. Post-transplantation sepsis from a suspected dental source was, for example, acknowledged in 27% of surveys of dental care protocols among US organ transplant centres and 80% of the respondents routinely requested a pre-transplant dental evaluation (Guggenheimer *et al.* 2005). Patients and their medical teams may justifiably seek advice on asymptomatic periapical lesions, whether identified on periapical radiographs or 3D images (Rustemeyer & Bremerich 2007, Olsen & van Winkelhoff 2014).

Further research is necessary to understand the nature of periapical radiolucencies identified on periapical radiographs and CBCT images and if there are any patient groups that are at special risk (Shendi *et al.* 2018). It may be that minimalist definitions of treatment success, such as tooth survival are insufficient to identify and manage risks. Equally, greater certainty is required on periapical radiolucencies that are resolving slowly, and whether they are likely to become a risk in susceptible patients. Other parameters related to quality of life and patient perceptions should also be considered in the decision-making process before planning further treatment (Liu *et al.* 2014, Leong & Yap 2019).

## Conclusion

The practice of judging endodontic outcomes on the basis of periapical radiographs may be insufficient to provide the answers that dentists and their patients need. Equally, if apical periodontitis is a significant disease in terms of local and systemic risks, then minimalist, patient-based outcomes such as tooth survival may be insufficient.

The current reality is that endodontic procedures are considered safe, effective and evidence-based to prevent and heal apical periodontitis and manage its associated risks. Endodontics must not, however, be complacent and a renewed era of scientific rigour is necessary to understand more fully the nature of the periapical radiolucencies that are detected with CBCT imaging, their healing dynamics, histological nature and risks they may present to vulnerable patient groups.

## References


Abella F, Patel S, Duran-Sindreu F, Mercadé M, Bueno R, Roig M (2012) Evaluating the Periapical Status of Teeth with Irreversible Pulpitis by Using Cone-beam Computed Tomography Scanning and Periapical Radiographs. *Journal of Endodontics* **38**, 1588–91.

Abella F, Patel S, Durán-Sindreu F, Mercadé M, Bueno R, Roig M (2014) An evaluation of the periapical status of teeth with necrotic pulps using periapical radiography and cone-beam computed tomography. *International Endodontic Journal* **47**, 387–96.

Ali AH, Koller G, Foschi F *et al.* (2018) Self-Limiting versus Conventional Caries Removal: A Randomized Clinical Trial. *Journal of Dental Research* **97**, 1207–13.

Al-Nuaimi N, Patel S, Austin R, Mannocci F (2017) A prospective study assessing the effect of coronal tooth structure loss on the outcome of root canal treatment. *International Endodontic Journal* **50**, 1143–57.

Al-Nuaimi N, Patel S, Davies A, Bakhsh A, Foschi F, Mannocci F (2018) Pooled analysis of 1-year recall data from three root canal treatment outcome studies undertaken using cone beam computed tomography. *International Endodontic Journal* **51**, 216–26.

Aminoshariae A, Kulild JC, Mickel A, Fouad AF (2017) Association between Systemic Diseases and Endodontic Outcome: A Systematic Review. *Journal of Endodontics* **43**, 514–9.

Bender IB (1982) Factors influencing the radiographic appearance of bony lesions. *Journal of Endodontics* **23**, 5–14.

Bender IB, Seltzer S (1961) Roentgenographic and direct observation of experimental periapical radiolucenices in bone: I. *Journal of the American Dental Association* **62**, 152–60.

Bornstein M, Lauber R, Sendi P, von Arx T (2011) Comparison of Periapical Radiography and Limited Cone-Beam Computed Tomography in Mandibular Molars for Analysis of Anatomical Landmarks before Apical Surgery. *Journal of Endodontics* **37**, 151–7.

Brynolf I (1967) A histological and roentenological study of the periapical region of human upper incisors. *Odontologisk Revy* **18**(Suppl 11).

Cheung GS, Wei WL, McGrath C (2013) Agreement between periapical radiographs and cone-beam computed tomography for assessment of periapical status of root filled molar teeth. *International Endodontic Journal* **46**, 889–95.

Cotti E, Dessì C, Piras A *et al.* (2011) Association of endodontic infection with detection of an initial lesion to the cardiovascular system. *Journal of Endodontics* **37**, 1624–9.

Davies A, Mannocci F, Mitchell P, Andiappan M, Patel S (2015) The detection of periapical pathoses in root filled teeth using single and parallax periapical radiographs versus cone beam computed tomography - a clinical study. *International Endodontic Journal* **48**, 582–92.

Davies A, Patel S, Foschi F, Andiappan M, Mitchell P, Mannocci F (2016) The detection of periapical pathosis using digital periapical radiography and cone beam computed tomography in endodontically retreated teeth - part 2: a 1 year post-treatment follow-up. *International Endodontic Journal* **49**, 623–35.

De Chevigny C, Dao TT, Basrani RB *et al.* (2008) Treatment Outcomes in Endodontics: The Toronto Study-Phase 4: Initial Treatment. *Journal of Endodontics* **43**, 514–9.

Doyle SL, Hodges JS, Pesun IJ, Law AS, Bowles WR (2006) Retrospective Cross Sectional Comparision of Initial Nonsurgical Endodontic Treatment and Single-Tooth Implants. *Journal of Endodontics* **32**, 822–7.

Ee J, Fayad M, Johnson B (2014) Comparison of Endodontic Diagnosis and Treatment Planning Decisions Using Cone-beam Volumetric Tomography Versus Periapical Radiography. *Journal Of Endodontics* **40**, 910–6.

Estrela C, Bueno MR, Leles CR, Azevedo B, Azevedo JR (2008) Accuracy of cone beam computed tomography and panoramic and periapical radiography for detection of apical periodontitis. *Journal of Endodontics* **34**, 273–9.

European Society of Endodontology (2006) Quality guidelines for endodontic treatment: consensus report of the

European Society of Endodontology. *International Endodontic Journal* **39**, 921–30.

European Society of Endodontology (2019) European Society of Endodontology Position Statement: Use of Cone Beam Computed Tomography in Endodontics. *International Endodontic Journal* **47**, 502–4.

Friedman S, Abitbol S, Lawrence HP (2003) Treatment Outcome in Endodontics: The Toronto Study. Phase 1: Initial Treatment. *Journal of Endodontics* **29**, 787–93.

Guggenheimer J, Mayher D, Eghtesad B (2005) A survey of dental care protocols among US organ transplant centers. *Clinical Transplant* **19**, 15–8.

Hashem D, Mannocci F, Patel S *et al*. (2015) Clinical and Radiographic Assessment of the Efficacy of Calcium Silicate Indirect Pulp Capping. *Journal Of Dental Research* **94**, 562–8.

Huumonen S, Ørstavik D (2002) Radiological aspects of apical periodontitis. *Endodontic Topics* **1**, 3–25.

Kanagasingam S, Hussaini H, Soo I, Baharin S, Ashar A, Patel S (2017a) Accuracy of single and parallax film and digital periapical radiographs in diagnosing apical periodontitis - a cadaver study. *International Endodontic Journal* **50**, 427–36.

Kanagasingam S, Lim C, Yong C, Mannocci F, Patel S (2017b) Diagnostic accuracy of periapical radiography and cone beam computed tomography in detecting apical periodontitis using histopathological findings as a reference standard. *International Endodontic Journal* **50**, 417–26.

Kirkevang L-L, Hørsted-Bindlev P (2002) Technical aspects of treatment in relation to treatment outcomes. *Endodontic Topics* **2**, 89–102.

Kruse C, Spin-Neto R, Evar Kraft DC, Vaeth M, Kirkevang LL (2019) Diagnostic accuracy of cone beam computed tomography used for assessment of apical periodontitis: an ex vivo histopathological study on human cadavers. *International Endodontic Journal* **52**, 439–50.

Leong DJX, Yap AU (2019) Quality of life of patients with endodontically treated teeth: A systematic review. *Australian Endodontic Journal* **20**, 0.1111/aej.12372.

Liu P, McGrath C, Cheung GS (2014) Improvement in oral health-related quality of life after endodontic treatment: a prospective longitudinal study. *Journal of Endodontics* **40**, 805–10.

Lofthag-Hansen S, Huumonen S, Gröndahl K, Gröndahl H (2007) Limited cone-beam CT and intraoral radiography for the diagnosis of periapical pathology. *Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology, And Endodontology* **103**, 114–9.

Low K, Dula K, Bürgin W, von Arx T (2008) Comparison of Periapical Radiography and Limited Cone-Beam Tomography in Posterior Maxillary Teeth Referred for Apical Surgery. *Journal Of Endodontics* **34**, 557–62.

National Joint registry 15th Annual Report 2018 (2018). https://www.hqip.org.uk/resource/national-joint-registry-15th-annual-report.

Newman HN (1996) Focal infection. *Journal of Dental Research* **75**, 1912–9.

Ng Y, Mann V, Gulabivala K (2010) Tooth survival following non-surgical root canal treatment: a systemic review of the literature. *International Endodontic Journal* **43**, 171–89.

Ng Y, Mann V, Gulabivala K (2011) A prospective study of the factors affecting outcomes of nonsurgical root canal treatment: part 1: periapical health. *International Endodontic Journal* **44**, 583–609.

Olsen I, van Winkelhoff AJ (2014) Acute focal infections of dental origin. *Periodontolology* **65**, 178–89.

Organ Donation and Transplantation Activity Report (2018/2019) https://nhsbtdbe.blob.core.windows.net/umbraco-assets-corp/16469/organ-donation-and-transplantation-activity-report-2018-2019.pdf.

Oriol I, Sabé N, Melilli E *et al*. (2015) Factors influencing mortality in solid organ transplant recipients with bloodstream infection. *Clinical Microbiology and Infection* **21**, 1104.e9–14.

Patel S, Wilson R, Dawood A, Foschi F, Mannocci F (2012) The detection of periapical pathosis using digital periapical radiography and cone beam computed tomography - Part 2: a 1-year post-treatment follow-up. *International Endodontic Journal* **45**, 711–23.

Patel S, Patel R, Foschi F, Mannocci F (2019a) The Impact of Different Diagnostic Imaging Modalities on the Evaluation of Root Canal Anatomy and Endodontic Residents' Stress Levels: A Clinical Study. *Journal of Endodontics* **45**, 406–13. https://doi.org/10.1016/j.joen.2018.12.001.

Patel S, Brown J, Pimentel T, Kelly RD, Abella F, Durack C (2019b) Cone beam computed tomography in Endodontics - a review of the literature. *International Endodontic Journal* **52**, 1138–52.https://doi.org/10.1111/iej.13115.

Paula-Silva F, Wu M, Leonardo M, Bezerra da Silva L, Wesselink P (2009) Accuracy of Periapical Radiography and Cone-Beam Computed Tomography Scans in Diagnosing Apical Periodontitis Using Histopathological Findings as a Gold Standard. *Journal Of Endodontics* **35**, 1009–12.

Rodríguez G, Abella F, Durán-Sindreu F *et al*. (2017a) Influence of cone-beam computed tomography in clinical decision making among specialists. *Journal of Endodontics* **43**, 194–9.

Rodríguez G, Patel S, Durán-Sindreu F, Roig M, Abella F (2017b) Influence of cone-beam computed tomography on endodontic retreatment strategies among general dental practitioners and endodontists. *Journal of Endodontics* **43**, 1433–7.

Rustemeyer J, Bremerich A (2007) Necessity of surgical dental foci treatment prior to organ transplantation and heart valve replacement. *Clinical Oral Investigations* **11**, 171–4.

Setzer FC, Hinckley N, Kohli MR, Karabucak B (2017) A Survey of Cone-beam Computed Tomographic Use among Endodontic Practitioners in the United States. *Journal of Endodontics* **43**, 699–704.

 

Shendi AM, Wallis G, Painter H, Harber M, Collier S (2018) Epidemiology and impact of bloodstream infections among kidney transplant recipients: A retrospective single-center experience. *Transplant Infectious Disease* **20**(1), e12815. https://doi.org/10.1111/tid.12815.

Uraba S, Ebihara A, Komatsu K, Ohbayashi N, Okiji T (2016) Ability of Cone-beam Computed Tomography to Detect Periapical Lesions That Were Not Detected by Periapical Radiography: A Retrospective Assessment According to Tooth Group. *Journal of Endodontics* **42**, 1186–90.

Venskutonis T, Daugela P, Strazdas M, Juodzbalys G (2014) Accuracy of digital radiography and cone beam computed tomography on periapical radiolucency detection in endodontically treated teeth. *Journal of Oral Maxillofacial Research* **5**, e1. https://doi.org/10.5037/jomr.2014.5201.

Weissman J, Johnson JD, Anderson M *et al*. (2015) Association between the Presence of Apical Periodontitis and Clinical Symptoms in Endodontic Patients Using Cone-beam Computed Tomography and Periapical Radiographs. *Journal of Endodontics* **41**, 1824–9.

Wu M-K, Shemesh H, Wesselink PR (2009) Limitations of previously published systematic reviews evaluating the outcome of endodontic treatment. *International Endodontic Journal* **42**, 656–66.