Preferred Reporting Items for Root and Canal Anatomy in the Human Dentition (PROUD 2020) – A Systematic Review and a Proposal for a Standardized Protocol

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ABSTRACT

Objective: Consistent reporting of publications in a given topic is essential. This systematic review aimed to identify and evaluate the reporting items in previous publications related to root canal anatomy in major Endodontic journals.

Methods: A systematic review was undertaken following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. A comprehensive literature search was performed by 2 independent reviewers using a customized search strategy in major Endodontic journals through Scopus until November 2019. Studies investigating root and canal anatomy were included. The selected publications were divided into 7 categories according to the study design: micro-computed tomography (microCT) and cone-beam computed tomography (CBCT) experimental studies (extracted teeth), CBCT and 2D clinical studies, CBCT and 2D case reports in addition to others (i.e. staining and clearing method and root sectioning). The selected studies were evaluated according to three domains: 1) Criteria for study sample selection; 2) Criteria for methodological procedures and 3) Criteria for detection and evaluation.

Results: After the removal of duplicated and irrelevant papers, 137 articles were included. Results showed that microCT studies reported accurately the tooth type, number of teeth, classifications used, qualitative and/or quantitative analysis (if required) and the evaluation process. However, sample size calculation, calibration, and reproducibility were not reported in the majority of microCT studies. CBCT clinical studies presented information for the type of study, inclusion/exclusion criteria, number of patients, tooth type, and number of teeth. However, the majority did not report sample size calculation and calibration of examiners. Radiographic exposure descriptions and classifications used were not reported adequately in CBCT and 2D case reports. Sample size calculation, calibration and reproducibility were not reported in staining and clearing method.

Conclusion: Despite accurate presentation of certain items, there is considerable inconsistent reporting of root and canal morphology regardless of the type of study and experimental procedure used. The PROUD checklist protocol presented in this systematic review aims to provide an accurate description of root canal anatomy in experimental, clinical, and case report publications.

Keywords: Morphology, protocol, reporting items, root canal anatomy, systematic review

HIGHLIGHTS

- This systematic review aimed to identify and evaluate the reporting items in previous publications related to root canal anatomy.
- Results showed that there is considerable inconsistent reporting of root and canal morphology regardless of the type of study and experimental procedure used.
- The PROUD checklist protocol presented in this systematic review paves the way for an accurate description of root canal anatomy in experimental, clinical, and case report publications.

INTRODUCTION

Effective root canal treatment requires a thorough knowledge of root canal anatomy (1). In the human dentition, a wide range of anatomical variations in each tooth type has been reported (1-4). For many decades, this topic has been the subject of numerous experimental reports in extracted teeth using different methodological procedures such as staining and clearing, 2D radiographic imaging, together with recent 3D technological advances including cone-beam computed tomography (CBCT) and micro-computed tomography (microCT), and others (4-9). This is in addition to CBCT clinical studies on different population groups, and 2D clinical studies as well as case reports that usually present anatomical variations and their detection methods using different imaging techniques, magnification, and other technical intra-operative procedures (2, 10-13).

Discrepancies and inconsistent reporting in studies may undermine the validity of the scientific effort, produce unfounded conclusions, and lead to the unnecessary repetition of studies with identical objectives (14). Current knowledge of root and canal morphology is based on research findings, clinical studies, and individual case reports (1, 4, 15). An accurate, consistent reporting of such information is essential. This would provide transparency in presenting a given data, facilitate accurate comparisons between different studies, facilitate the combination of quantitative and qualitative results from previous studies and present a high-quality reference to researchers and clinicians guiding them to build up high-quality research and satisfactory standards of clinical care, respectively.

Unfortunately, there is a lack of evidence for the level of consistent reporting in publications related to root and canal anatomy. This systematic review aimed to (1) extract and evaluate the reporting items related to root and canal anatomy in experimental and clinical studies as well as case reports published in major Endodontic journals; (2) introduce a protocol for consistent reporting of root and canal anatomy which can be applied in experimental and clinical studies and case reports.

MATERIALS AND METHODS

The current systematic review was prepared following the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) statement (16).

Literature search methodology

An electronic search was performed in the Scopus database (www-scopus-com). The following keywords were used – "root canal morphology" OR "root canal anatomy" OR "root canal configuration" OR "accessory canals" till November 2019. The search in Scopus was limited to four endodontic journals - Journal of Endodontics, International Endodontic Journal, Australian Endodontic Journal, and Oral Surgery Oral Medicine Oral Pathology Oral Radiology and Endodontology (until 2011) and previous names of this journal.

Inclusion and exclusion criteria
a) Root canal anatomy:

Studies investigating root and canal anatomical variations in the human permanent dentition such as the number of roots, root canal configurations, morphology of the canal isthmuses, and accessory canals were included. Main classifications for root and canal anomalies such as radix entomolaris, C-shaped canals, dens invaginatus, palato-gingival grooves, taurodontism were included. The methods of detection, description, and classifications of root canal anatomy were recorded. The treatment procedures proposed for such anatomical variations were excluded.

b) Publication type:

Experimental and clinical studies as well as case reports were included in this systematic review. Case report publications having literature reviews were included. Literature reviews, editorials, and other publication types were excluded. Studies comparing different methodological procedures to assess root canal morphology were also excluded.

c) Experimental methods:

(i) Experimental studies related to microCT were included.

(ii) Experimental and clinical studies as well as case reports related to CBCT were included. Spiral computed tomography reports were excluded.

(iii) For 2D radiographic imaging, clinical studies were included, and for case reports, the most cited 10 publications and all reports published since 2010 were included.

(iv) For staining and clearing techniques (and others if applicable), all studies that were used as a reference to classify root canal morphology in the CBCT and microCT studies fitting the criteria of this systematic review were included.

Data extraction and analysis procedures
Phase 1:

Using the above-mentioned literature search methodology and inclusion criteria, the titles and abstracts were screened by 2 independent reviewers to identify the publications after duplicates removal. Using online kappa calculator (https://idostatistics.com/cohen-kappa-free-calculator/#risultati), the Cohen's kappa analysis was calculated, and the level of agreement was determined.

Phase 2:

The selected studies were read in full text, and reviewed by the 2 independent reviewers, and a discussion was undertaken for the selection and collection of reporting items for each of the following categories:

a) Research studies:

These included (i) studies investigating root canal anatomy in "extracted teeth" using 3D methods (microCT and CBCT), in addition to other methods (such as staining and clearing) as mentioned in the inclusion criteria; (ii) studies investigating root canal anatomy in patients/population groups using CBCT or 2D radiographic imaging.

This category was divided into 3 domains:
Domain A: Study design and sampling method:

This domain included the type of study (e.g. experimental, clinical, ethical approval, a priori sample size calculation, population/ethnic group, tooth type, number of teeth, number, gender and age of patients (or donors/owners, if applicable), inclusion/exclusion criteria. The latter criteria were scored as present if the authors mentioned accurate details for the included samples (e.g. the presence of caries, root canal fillings, restorations, resorption defects, mature roots).

Domain B: Experimental/diagnostic procedures:

This domain included the details of the experimental method including the type of radiographic machine/scanner and specifications/settings [such as kilovoltage (Kv), milliamperage (mA), voxel size and field of view (FOV) (if applicable)]. If 2D radiographic imaging was used, details on angulation techniques (perpendicular to the horizontal plane, mesial, distal shift angulations) and image processing (digital or manual) were evaluated. Magnification, modified access cavities, exploration, negotiation with and without troughing were included in instances of studies that examined the detection

of canals. Experimental procedures for staining and clearing were also evaluated.

Domain C: Evaluation process:

This domain included details for the evaluation objectives and methods used such as qualitative (e.g. root and canal configurations, presence/absence of C-shaped canals) and/or quantitative analysis (e.g. canal volume, thickness, distance between canal orifices), how the evaluation process was performed and software used. In addition, calibration, reproducibility of observers (e.g. Kappa score), classifications used for identification and statistical analysis were also evaluated.

b) Case reports:

These included CBCT and 2D radiographic case reports (or series).

This category was divided into 3 domains:

Domain A: Case description details

This domain included the population/ethnic group, tooth type, number of teeth, age, and gender of patients.

Domain B: Diagnostic procedures:

This domain included the details of radiographic machine/scanner and settings (such as Kv, mA and voxel size if applicable) and field of view (if applicable), in addition to other clinical procedures used for detection of canals such as magnification, modified access cavities, exploration, negotiation with and without troughing.

Domain C: Evaluation process:

This domain included the narrative details for the evaluation objectives and methods used such as qualitative and/or quantitative analysis, how the evaluation process was performed using the software, and classification used for identification.

Phase 3:

Each of the assessed items was dichotomized as present or absent by the authors. For calibration, the two independent reviewers have undertaken a pilot study in which 20 selected publications were analyzed in an Excel spreadsheet. Disagreements between reviewers were discussed until a decision was obtained by consensus.

Phase 4:

The two independent reviewers analyzed the included publications in each category, and a Cohen's kappa analysis (https://idostatistics.com/cohen-kappa-free-calculator/#risultati) was calculated for each category. Disagreements between reviewers were discussed via emails, and discussion calls were considered, if needed, until a decision was reached by consensus.

Phase 5:

After data analysis and synthesis, a checklist protocol was developed for each of research and case report categories.

RESULTS

The search strategy results are presented in Figure 1. A total of 138 studies were included in this systematic review [37 microCT studies (17-53), 4 CBCT experimental studies (9, 54-56), 38 CBCT clinical studies (2, 10, 57-92), 10 2D clinical studies (11, 93-101), 12 staining and clearing and root sectional studies (including one study for tooth sectioning) (7, 102-112), 14 CBCT case reports (12, 113-125) and 22 2D case reports (13, 126-146)]. For phase 1, the agreement between reviewers was 90.05% (Cohen's k=0.76 – substantial agreement). Table 1 shows Cohen's kappa analysis for research studies and case reports.
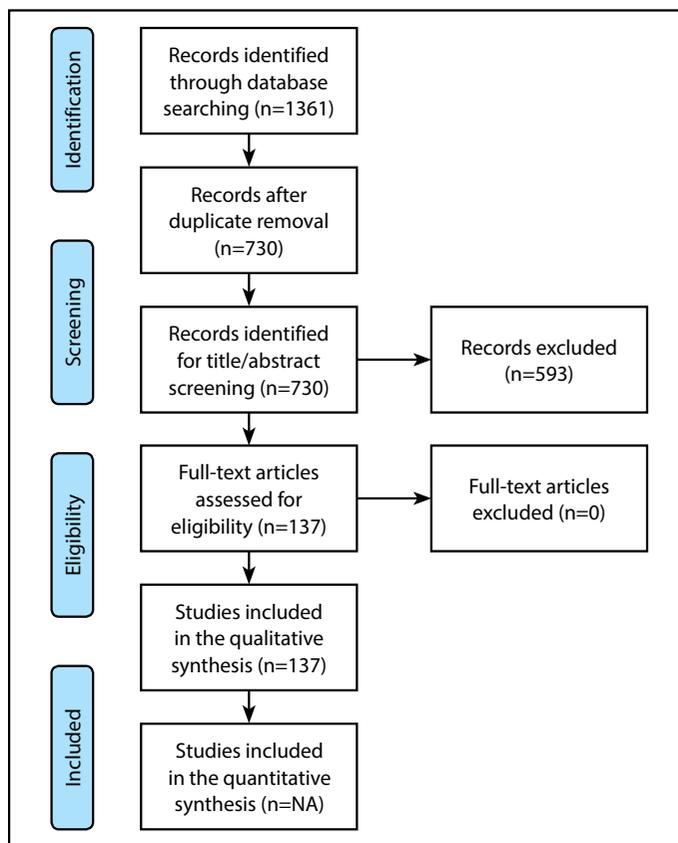

Figure 1. PRISMA flowshart of this systematic review

TABLE 1. Cohen's kappa analysis for all study categories included in this systematic review

Categories	Number of publications included	Agreement percentage bet. reviewers	Cohen's kappa	Level of agreement
MicroCT studies	37	89.61%	0.79	Substantial
CBCT experimental studies	4	86.1%	0.67	Substantial
CBCT clinical studies	38	90.7%	0.75	Substantial
2D clinical studies	10	88.84%	0.77	Substantial
Staining and clearing studies	12	98.0%	0.96	Almost perfect
CBCT case reports	14	96.3%	0.92	Almost perfect
2D case reports	22	91.6%	0.83	Almost perfect
Total/mean	137	91.59%	0.81	Almost perfect

Results showed that all microCT studies presented the type of study, tooth type, number of teeth, and classifications used. The majority of studies described qualitative and/or quantitative analysis (if required) and the evaluation process (Fig. 2). However, a priori sample size calculation was not mentioned in any of the studies. Information related to age and gender of tooth donors/owners was not provided in the majority of studies; as often this information was not available since the teeth were extracted previously due to reasons not related to the studies. Only two studies provided details for calibration (21, 38), and none for reproducibility test. Four studies mentioned agreement consensus between examiners (21, 32, 35, 41).

About half of the included studies did not provide information regarding ethical approval (19, 23, 25, 28, 30, 32-35, 37, 40, 43, 46, 51-53), or related ethnic group/population (18, 20, 22, 28-31, 35-38, 41, 42, 45-47, 50, 51), or complete description of imaging settings (machine brand, Kv, mA, voxel size) (19, 20, 28-30, 32, 35-38, 40, 41, 45, 47, 51-53). The inclusion and exclusion criteria were not mentioned in 4 studies (19, 28, 49, 53), and were considered incomplete in 13 studies (26, 29, 31, 37, 38, 40, 44-48, 51, 52). Less than half of the studies did not perform statistical analysis.

For CBCT experimental studies in extracted teeth, similar to microCT studies, all investigations included information related to the type of study, tooth type, tooth number and description of evaluation process, but none of the studies provided details regarding sample size calculation. Only one study provided information for ethical approval (55), and the calibration of examiners (56). One study did not mention the inclusion/exclusion criteria (54). Agreement between observers was performed in 3 studies (54-56). Two out of 4 studies provided information related to scanner type and imaging settings used (Kv, mA, voxel size and FOV) (9, 56). Similar to microCT studies, information related to age and gender of the teeth donors/owners was not provided in any study (Fig. 3).

For CBCT clinical publications, results showed that all studies presented information for the type of study, inclusion/exclusion criteria, number of patients, tooth type, and number of teeth (Fig. 4). Few studies did not provide details on ethical
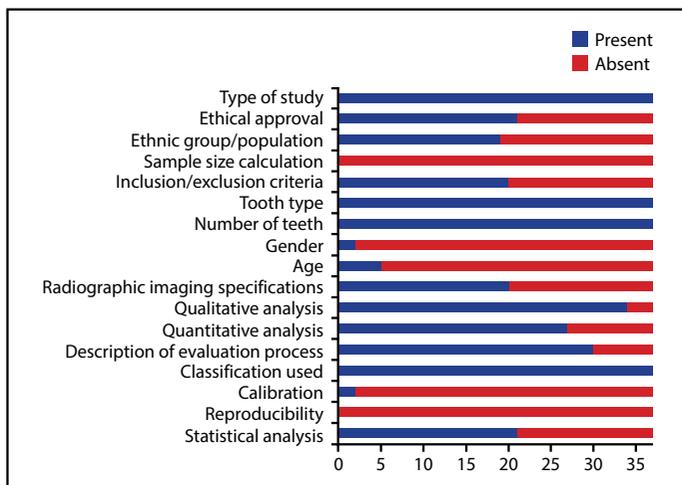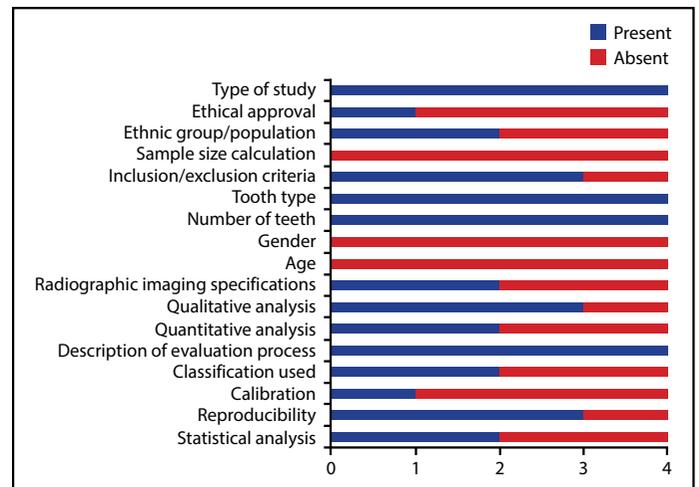

Figure 3. Bar chart for reporting items related to CBCT experimental studies

approval (61, 64, 66, 75, 84, 85), ethnic group/population (78, 88-90) and gender (71, 79, 80, 89).

A number of CBCT clinical studies did not provide complete information on radiographic imaging specifications (machine, Kv, mA, voxel size and FOV) (10, 59, 60, 64, 66, 71, 74, 75, 79, 80, 84, 85, 87, 89), morphology classifications used (57, 59, 67, 78, 85, 88, 89, 91), and statistical analyses (68, 72, 75, 77, 82, 83, 85) (Fig. 4). More than half of the studies did not provide details on the calibration of examiners (2, 10, 57, 60, 61, 66, 71, 73-76, 78-83, 86, 88, 89), and 42% did not provide details for the analysis of agreement between observers (or same operator after a given time) assessment. While few studies did not mention details on the agreement per se (10, 58, 75, 86, 89), some studies mentioned different ways for reporting agreement (without analysis) either by consensus reached between examiners (64, 66, 67, 72, 76, 77, 81-83), or were resolved by a third reviewer (63, 71, 74, 79, 80, 91, 92). Only 6 out of 38 studies (16%) reported sample size calculation (57, 59, 64, 67, 78, 91).

For 2D clinical studies, results showed that included studies presented the type of study, tooth type, the number of teeth and qualitative analysis of radiographic images (Fig. 5). None
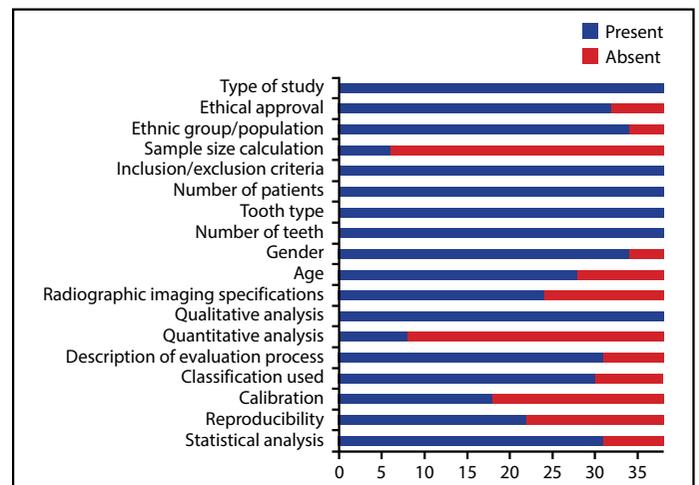

Figure 2. Bar chart for reporting items related to microCT studies

Figure 4. Bar chart for reporting items related to CBCT clinical studies

of the studies provided information regarding sample size calculation or complete information on radiographic imaging specifications (machine, Kv, mA, angulation technique and processing). Five studies provided details on the angulation used for imaging (11, 93, 95, 99, 101). Ethical approval was mentioned in only 2 studies (11, 95), whereas 5 studies provided information regarding the ethnic group/population assessed (11, 93, 95, 96, 100). The majority provided information for age (11, 93, 95, 98-101), and less than half mentioned details on gender of the patients/subjects (93, 95, 99, 100).

Results showed that half of the 2D clinical studies reported the use of magnification for detection of canals (11, 94-96, 99). Clinical procedures performed to detect canals were mentioned in details, and varied based according to the aim of the study including modification of the access cavity (11, 93, 94, 99, 100), exploration (mainly using DG16) (11, 93-95, 98, 99), negotiation with hand files without troughing (95) or negotiation with troughing using ultrasonic tips or long shank round burs (11, 93, 94, 96, 98, 99) (Fig. 5). The root canals were either described based on a given classification such as Weine's classification, (11, 93, 97-99) or without (94-96, 100, 101).

2D clinical studies reported a wide variations for the operators performing the clinical procedures; a single operator treated the cases in four studies (11, 94, 100, 101), two endodontists in two studies (93, 99), postgraduate students in one study (96) and three operators in another study (97), whereas this information was unclear in two studies (95, 98). No information was provided in any study with regards to calibration of operators. Only one study (93) provided details with regards to the number of years of experience of each operator. Reproducibility was not applicable since the treatment is carried out once.

Notably, two 2D clinical studies (147, 148) were not included in the bar chart since they evaluated the root and canal morphology using 2D radiographic imaging with different angles in the absence of clinical intervention.
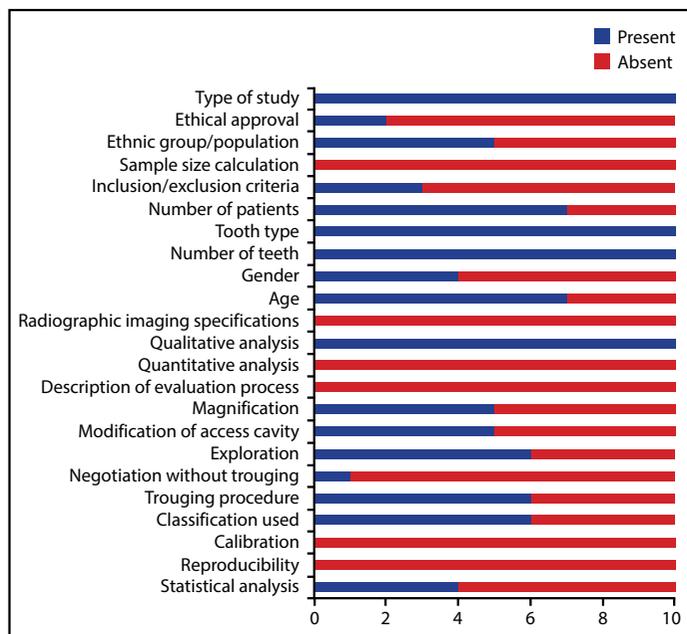
For other type of studies, results showed that staining and clearing and root sectioning publications did not provide details for ethical approval, sample size calculation, calibration or reproducibility (Fig. 6). About half of the studies provided details on ethnic groups/populations. Only two out of 11 studies listed the inclusion and exclusion criteria (111, 112). Only 1 study provided details on gender of the teeth donors/owners (103), and reported statistical analysis (110). Similarly, Weine's study (107), which was a sectioning experimental study performed on the mesiobuccal roots of extracted maxillary molars, did not perform sample size calculation, calibration and reproducibility, and did not mention inclusion/exclusion criteria (Fig. 6).

For case reports, results showed that all CBCT publications presented age and gender of patients, tooth type, and number of teeth. Three reports mentioned the ethnic group/population of the patients (115, 116, 119). In general, complete details for radiographic imaging specifications (Kv, mA, voxel size, FOV) were not provided in any report. However, incomplete information was provided in some reports; twelve reports mentioned details on machine type (12, 113-117, 119, 121-125), 7 reports for Kv and mA (12, 116, 117, 119, 121, 122, 124), and none for FOV. All reports provided details for qualitative analysis (mainly root and canal configuration). Quantitative measurements were performed in one report (114). Description of the evaluation process was performed in 3 reports (116, 117, 119). Magnification was used in the majority of reports. The clinical procedures performed to detect canals were described in details, and varied based on the aim of the study (i.e. detection of canal orifices or apical canal bifurcations) (Fig. 7). Six reports provided details on the classification used (12, 115, 119, 123-125).

For 2D case reports, almost all publications presented information for the number, age, and gender of patients, tooth type, number of teeth and qualitative analysis of the radiographic views. Seven out of 22 reports mentioned the ethnic group/population of the patients (126, 127, 130, 131, 141, 143, 144). None of the reports provided complete information for radiographic imaging specifications (Kv, mA, angulations) or quantitative analysis or description of the evaluation process. Three reports provided information on the radiographic angulations used (126, 127, 139). Nine reports provided details on the con-

Figure 5. Bar chart for reporting items related to 2D clinical studies
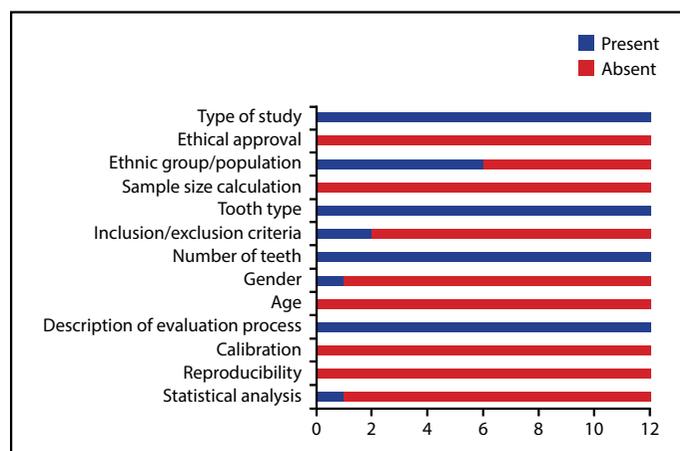

Figure 6. Bar chart for reporting items related to classifications used staining and clearing

*Weine's classification (107) is included in this chart (sectioning in extracted teeth)
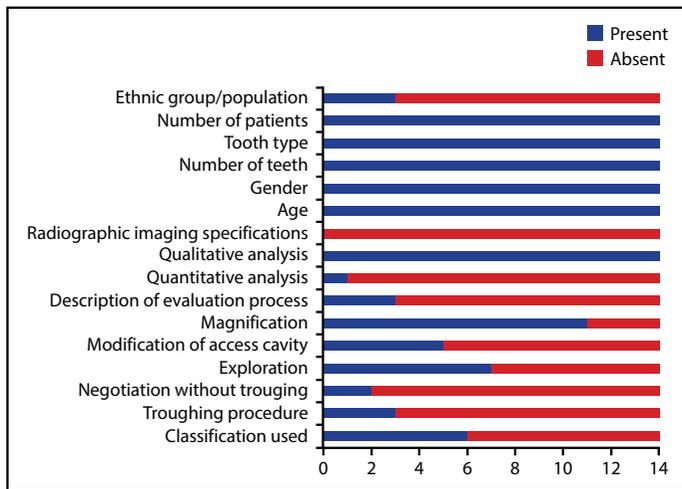
Figure 7. Bar chart for reporting items related to CBCT case reports

figuration classification used (13, 126, 128, 132, 133, 135, 138, 144, 146). Magnification was used in 14 publications (13, 126-129, 132-136, 143-146). Clinical procedures performed to detect canals were often mentioned explicitly, and varied based on the aim of the study (i.e. detection of canal orifices or apical canal bifurcations) (Fig. 8).

DISCUSSION

Consistent reporting is an essential requirement in scientific publications (14). This systematic review aimed to evaluate the level of consistency for listing the reporting items related to root and canal anatomy publications. In general, for studies, results showed that despite the included publications provided accurate details on items related to the study type, tooth type, number of patients and teeth, there are obvious deficiencies to describe sample size calculations, calibration, reproducibility, inclusion/exclusion criteria, and ethnic groups/population. On the other hand, radiographic imaging specifications, technique, and processing together with describing the anatomy using a given classification were the main deficiencies for case reports.

Literature shows that different ethnic groups may show different root canal anatomical variations in the human denti-
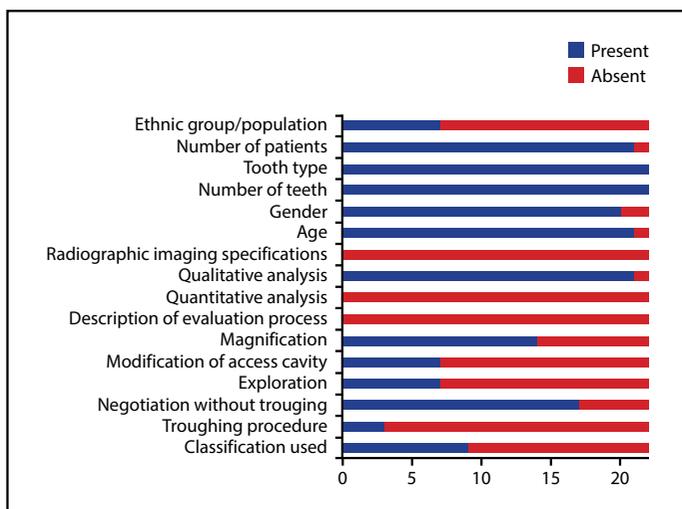

Figure 8. Bar chart for reporting items related to 2D case reports

tion (4, 59). Except for CBCT clinical studies, this systematic review showed that more than half of the studies included, as well as case reports, did not mention the ethnic group or population of the examined teeth. One possible explanation that many countries, nowadays, are often populated by multiple ethnic groups; it seems complicated to accurately identify the origin of the study samples, especially if the study was performed on teeth extracted for reasons not related to that particular study. Furthermore, one country may have cities with various ethnic groups. Nevertheless, it is essential for authors to describe the nature of the ethnic group/population where the teeth were extracted (or the patients included). This would provide a consistent database source for future studies and systematic reviews to compare and propose valid conclusions.

Sample size calculation is usually performed at the time of planning a given study, and it varies according to the type of research question and study design. Whatever be the aim, if a hypothesis is being tested, sound conclusions can be drawn only with an appropriate sample size (149). Very often, a limited sample size is decided arbitrarily based on the researchers' convenience, available time, and resources, resulting in potentially misleading findings due to an insufficient number of subjects studied (149). A very large sample size is also not recommended since it is a waste of available resources if an answer can be accurately achieved with a smaller sample, as long as there is sufficient power in the test (149).

Results of this systematic review showed that the sample size calculation was not reported in any of the microCT studies, experimental CBCT studies or staining and clearing studies. Only 6 out of 38 CBCT clinical studies reported sample size calculations (57, 59, 64, 67, 78, 91). It is well-known that microCT scanning of extracted teeth is an expensive procedure, and it requires a long time for scanning followed by sophisticated qualitative and quantitative analysis. However, reporting the sample size calculation is still essential to confirm that the results represent a given population of a particular tooth type. Similarly, a recent systematic review discussed microCT studies on rodent jawbone micro-architecture (150), and reported that none of the 46 included microCT studies performed sample size calculation, which was considered as one deficiency (150). Despite that ethical approval does not has an impact on root canal identification, it was included it in this systematic review because in addition to its legal and moral relevance, it may give a clue to other related items such as sample size calculation which is usually documented in ethical approval applications. Except for CBCT clinical studies, the majority of experimental investigations and 2D clinical studies did not mention information on ethical approval, which is considered as another deficiency in reporting.

Establishing inclusion and exclusion criteria is required when designing high-quality research protocols. Except for CBCT clinical studies, this systematic review showed that more than half of the studies did not provide accurate, detailed inclusion/exclusion criteria for the study samples. Few studies did not provide any details, and some provided incomplete criteria. For example, some studies mentioned the selection of teeth

with a definite number of roots (some mentioned with fully formed apices and others did not) but with no details on the presence/absence of carious lesions, resorption defects, restorations, root canal fillings and others (26, 44, 45, 47). Notably, applying strict inclusion/exclusion criteria for selection of teeth with rare anatomical variations (such as three rooted maxillary premolars and maxillary incisors with palato-gingival grooves) could be challenging. However, it is important for authors to provide a detailed description of such criteria to ensure that the teeth were selected correctly with no confounding factors that may alter the anatomical features of the crown and/or root canal space.

Literature shows that ethnic groups/population, age and gender (with lesser extent) play a role in root canal anatomical variations (60, 61, 151). Except for CBCT clinical studies and case reports (CBCT and 2D), results showed that these items were rarely or less commonly reported in microCT, experimental CBCT and staining and clearing studies as well as 2D clinical studies. Listing such details is beneficial for accurate comparisons between study findings and providing valid explanations for potential differences; however, obtaining such information for extracted teeth is challenging since they are usually collected from hospitals and dental clinics, and patients' details are usually unavailable.

Radiographic imaging specifications for both 2D and 3D imaging procedures, in addition to the software used for qualitative and quantitative analysis may influence the image quality and interpretation of canal anatomy (152, 153). This systematic review showed insufficient reporting of radiographic imaging specifications in all diagnostic methods, especially 2D clinical studies, CBCT and 2D case reports (Figs. 2-5, 7, 8). With the exception of CBCT and 2D clinical studies and 2D case reports, the majority of microCT and CBCT studies described the evaluation procedures, and how the qualitative and quantitative analyses were performed (Figs. 2-5, 7, 8). Such information has to be mentioned in studies and case reports for the reviewer to evaluate, the reader to understand and the researcher to refer when designing a future research.

In addition to the radiographic observations for the presence of additional canals either by presence of a "breakpoint" or canal bifurcations in different radiographic angulations, deviation of a previous filling material to one side of the canal, penetration of the root filling material into a missed canal space or CBCT (11, 119, 142), the description of clinical procedures used for detection of root canals is beneficial to the reader. Based on analysis of studies and case reports included in this systematic review, magnification (operating microscopes and loupes), modification of the access cavity, exploration (using DG16 or other), negotiation using K-files, troughing between canal orifices using ultrasonic tips or long shank burs (Figs. 5, 7, 8), in addition to other clinical landmarks such as presence of a bleeding point or sodium hypochlorite bubbling or staining of the pulp chamber floor (129, 135), have been reported.

Weine's (107) and Vertucci's classifications (and its supplemental configurations) (102-106, 108) are the most commonly used systems used to classify the root and canal morphology and, along the years, they have been used as the main references to describe the root and canal morphology in current publications using microCT, CBCT and others. In addition to some deficiencies in reporting some items related to inclusion/exclusion criteria, calibration and reproducibility, the authors have noticed the presence of inconsistent use of both classifications. For instance, in Weine's classification, the floor of the pulp chamber was taken as a reference for the root canal orifice in the MB root of maxillary molars (107), but no information was given to the location of the orifice in single rooted teeth. Similarly, Vertucci's classification did not define the location of the canal orifice, and it was defined later in his publication as "A root canal begins as a funnel-shaped canal orifices generally present at or slightly apical to the cervical line" (1), with no definition to this "slight apical" position. One possible reason is that Vertucci's classification was based on staining and clearing method in which teeth were subject to decalcification, staining and clearing; such procedures significantly deteriorate the normal anatomical features of the tooth, including the CEJ, thus making its identification, in some samples, rather challenging. Secondly, the pulp chamber floor location may not coincide with the CEJ (located slightly apical) (1). Unfortunately, the majority of studies and case reports included in this review did not define the location of root canal orifice. Based on the above, it is obvious that the root canal orifice level should be explicitly defined in any related publication. Similar concerns have been raised for intercanal communications - whether they are part of the root canal configurations or not (154). Recently, a number of concerns and considerations have been discussed, and a new coding system has been introduced for accurate description of the root and canal morphology, accessory canals and anomalies (155-157).

Experimental and clinical observations must be reliably measured by calibrated examiners, preferably over time, to be interpreted with confidence (158). This is of particular importance during visual inspection of root canal configuration types, morphology of canal orifices and other morphological variations in 2D and 3D radiographic views, 3D reconstruction images and other conventional methods. This systematic review showed that the majority of studies did not report calibration of examiners or reproducibility tests. It is worth noting that calibration of the machine used for testing and performing measurements is also essential before undertaking quantitative analysis, and this was rarely reported in microCT studies (36, 41).

Statistical methods play an important role in dental research. Due to the developments in computer technology, computationally more demanding and novel statistical methods have also been applied more often (159). This probably justifies the reason for the increased use of inferential statistical analysis in recent root canal anatomy publications comprising qualitative and quantitative presentations compared to staining and clearing studies which mainly describe the root canal configuration types. It is important to note that statistical significance in anatomy publications does not necessarily equate with clinical significance, especially when describing minor details of the root canal system such as angles between canal orifices and length of accessory canals (18, 49).

A Proposal for a Standardized Protocol – P̲referred R̲eporting Items for R̲o̲o̲t and Canal Anatomy in the H̲u̲man D̲entition (PROUD 2020)

This systematic review aimed to present the general mapping of reporting items related to root and canal morphology, and provide recommendations for consistent reporting in experimental and clinical studies as well as case reports. Based on the discussion above, it appears that a checklist is needed to help authors to document all necessary information required for consistent reporting, and equip researchers and clinicians with the information needed for future studies and reports. It will also help reviewers and editors to check such items during the reviewing process, especially with the development of new software programs with high-quality images, and differ-

ent modes to enhance the visualization of complex anatomical structures (152, 160, 161).

The PROUD checklist for studies and case reports are designed based on the items extracted and evaluated in this systematic review (Tables 2, 3). The checklist is divided into three components: type of study/report, items for reporting study samples, and items for reporting the evaluation process. For simplicity, the checklists for studies and case reports are designed in a similar manner; but sample size calculation, inclusion/exclusion criteria and statistical analysis are excluded from the checklist for case reports. In the last column for both tables, the author(s) has/have to mention the page number where the items are reported in their sub-

TABLE 2. Reporting items for root and canal morphology in research studies

Section	Number	Checklist item	Listed on page number
Type of study	1	Experimental or clinical (cross-sectional or other); retrospective or prospective	
Ethical approval	2	Approval from the ethical board committee	
Ethnic group/population	3	Details on ethnic group or population	
Tooth type (or roots)	4	Tooth (teeth) type included in the study and/or roots	
Sample size calculation	5	Information on how the sample size was calculated before undertaking the research	
Number of teeth (and/or roots)	6	The number of study samples should be reported.	
Inclusion/Exclusion criteria	7	Information on how the teeth were selected – e.g. caries, resorption defects, restoration, root canal treated teeth, mature root apex, fractures, etc. Other factors related to imaging/processing issues such as artifacts or samples loss because of chemicals (such as staining and clearing) have to be mentioned as criteria for exclusion.	
Age	8	If applicable, the age range (or groups) of the study samples or patients should be reported.	
Gender	9	If applicable, the gender of study samples should be reported.	
Diagnostic device specifications and technique	10	Radiographic machine: This includes machine type, exposure settings Kv, mA, voxel size (if applicable), FOV (if applicable), angulation techniques, etc, as well as software programs used for analysis. Other diagnostic tools (such as staining and clearing, SEM, etc): The specifications and procedures should be mentioned in details. For all, calibration of the machine (if applicable) should be reported.	
Qualitative analysis	11	Such as root canal configurations, evaluation of root canal shapes.	
Quantitative analysis	12	Such as measuring volumes, areas, diameters, distances, angles.	
How the evaluation process was performed	13	Such as examining the coronal/axial/sagittal sections in 3D imaging, or observing the canal bifurcations in 2D imaging under magnification, etc.	
Endodontic procedures (if applicable)	14	Magnification, modification of the access cavity, exploration, negotiation with our without troughing and others (applicable for 2D clinical studies).	
Classification used	15	Classification used for root canal configurations (with clear definition for orifice location and intercanal communications), root anomalies, accessory canals.	
Calibration and reproducibility	16	How the examiners were calibrated. Methods for calibration must be described clearly. Intra-rater and/or inter-rater reliability tests must be mentioned.	
Statistical analysis (if applicable)	17	The type of statistical method and software used for analysis should be reported.	

TABLE 3. Reporting items for root and canal morphology in case reports

Section	Number	Checklist item	Listed on page number
Type of report	1	Case report, case series.	
Ethnic group/population	2	Details on ethnic group or population	
Age*	3	The age range of the patient(s) must be reported.	
Gender*	4	The gender of patient(s) must be reported.	
Tooth type	5	Tooth (teeth) type included in the report.	
Number of teeth included	6	Number of teeth included in the report.	
Diagnostic device specifications and technique	7	This includes machine type, exposure settings Kv, mA, voxel size (if applicable), FOV (if applicable), angulation techniques, etc. Software(s) used for the analysis.	
Qualitative analysis	8	Such as root canal configurations, evaluation of root canal shapes.	
Quantitative analysis	9	Such as measuring volumes, areas, diameters, distances, angles.	
How the evaluation process was performed	10	Such as examining the coronal/axial/sagittal sections in 3D imaging, or observing the canal bifurcations in 2D imaging under magnification, etc.	
Magnification	11	Operating microscope or dental loupes or other. Magnification step and assisted illumination (if used) have to mentioned.	
Modification of the access cavity	12	Conventional or changing the access cavity configuration to detect anatomy.	
Exploration	13	Such as DG16 or other explorers.	
Negotiation with or without troughing	14	Using ultrasonic tips or burs (troughing) or pre-curved files (without troughing).	
Other special clinical observations	15	Such as bleeding point, NaOCl bubbling, etc.	
Classification used	16	Classification for root canal configurations (with clear definitions for the orifice location and intercanal communications), root anomalies, accessory canals, etc.	

*In few occasions, case reports may have a presentation of both clinical case and extracted tooth – authors can mention "NA" if related information were not recorded for the extracted tooth

mission. This would facilitate the reviewing process for editors and reviewers. Figures 9-13 show examples for reporting studies and case reports based on the PROUD proposed protocol.

It is worth noting that other methods have been reported to investigate the anatomical features of the root and canal "in extracted teeth" such as 2D radiographic imaging (162), scanning electron microscope (SEM) (5), stereomicroscope (6), cross sectional methods (163), and optical coherence tomography (164). Despite that these methods are less commonly used, the proposed checklist is applicable since all anatomy publications share similar reporting items for selection of the study samples, and the evaluation section listed in Table 2 can be applied for reporting other experimental procedures.

In addition to journals specialized in the field of pediatric dentistry, Endodontic journals have given a space for publications related to root and canal morphology as well as root canal treatment procedures in the primary dentition (165, 166). The checklist presented in this systematic review can be used for reporting root and canal anatomy in the primary teeth. Indeed, inclusion and exclusion criteria should have details for the stage of physiologic root resorption of the study samples

(such as extracted primary molar teeth in which resorption does not exceed one third of root length) (167).

Recently, a number of developmental protocols have been introduced related to reporting guidelines in case reports (168), observational (169) and laboratory studies (170) in addition to clinical trials and animal studies (171, 172). These guidelines aim to improve the quality, accuracy and transparency of case reports and studies. For instance, the preferred reporting Items for case reports in Endodontics (PRICE) checklist (168) is composed of items including the title, abstract, introduction, informed consent, case report information including patient details such as age, gender, ethnicity, chief complain, medical and dental history, extra-oral findings in addition to diagnostic methods used, active treatments and outcomes followed by a number of items to be covered in the discussion section and conclusion. Obviously, following these guidelines "in general" is beneficial to authors, and they are important steps for more accurate and consistent reporting in Endodontics. The present systematic review aimed to present a comprehensive analysis, detect deficiencies of the current literature, and provide a detailed protocol for studies and case reports related to root and canal anatomy with emphasis to "more specific" items (such as how the canals were identified radiographically and clinically, classification used for describing the canal morphology, etc)
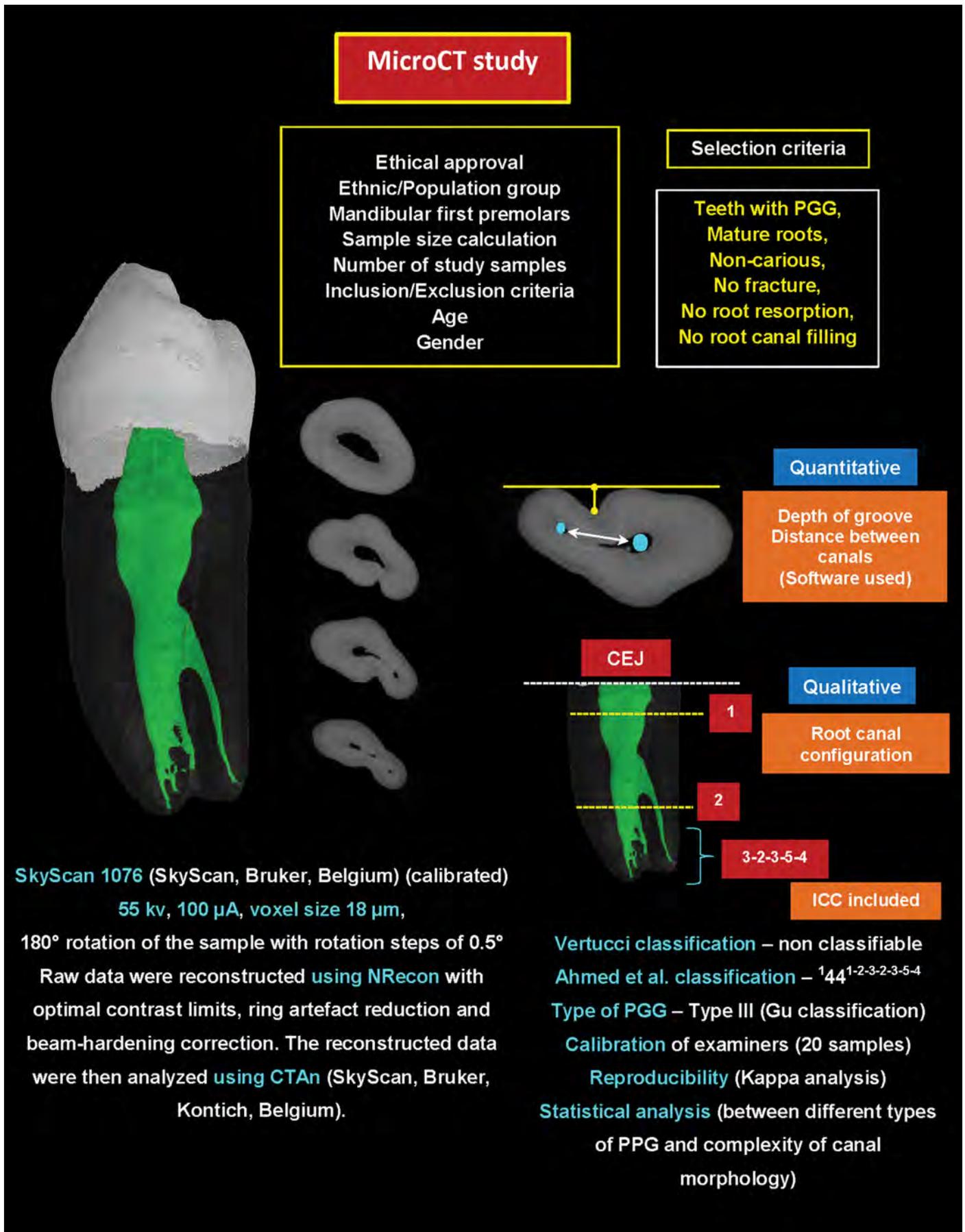
Figure 9. An example for reporting anatomy in a microCT study. PGG: Palato-gingival groove. MicroCT images from Root canal anatomy project lead by HMA Ahmed and NS Mohamed (2020). PGG – Palato-gingival groove, ICC – Intercanal communication
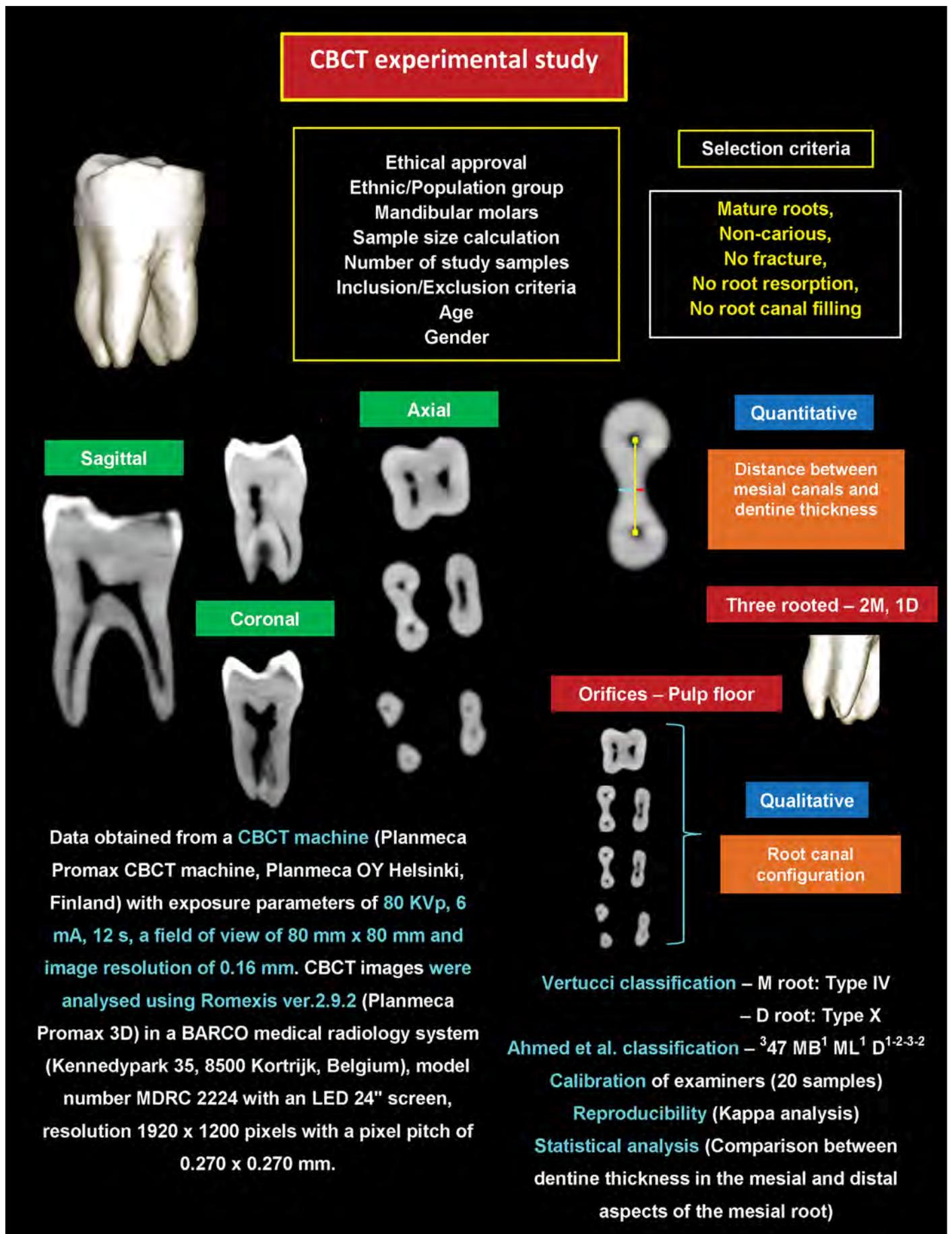
Figure 10. An example for reporting anatomy in an experimental CBCT study (extracted teeth)
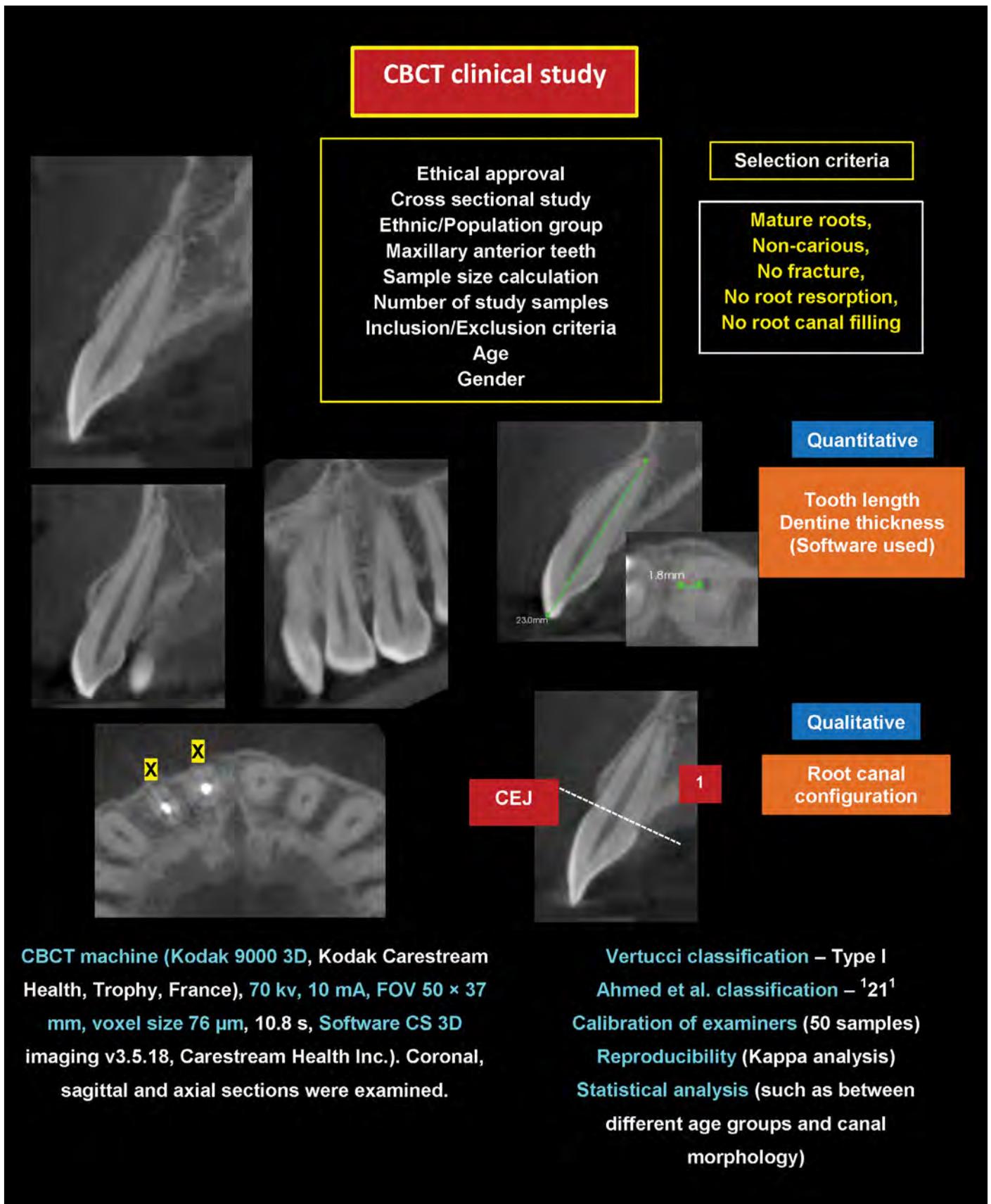
Figure 11. An example for reporting anatomy in a clinical CBCT study – X: Excluded because of root canal filling

that have to be mentioned in order to provide an accurate and consistent reporting of root and canal anatomy. The ability of researchers and clinicians to present their studies or reports with clear, accurate items from title to conclusions with special attention to fine details related to the main objective of the report (such as root canal anatomy) is necessary.

Figure 12. An example for reporting anatomy in a clinical study

Figure 13. An example for reporting anatomy in a case report. Number of patients (and teeth included) should be provided in case series

CONCLUSION

There is considerable inconsistent reporting of root and canal morphology regardless of the type of study and experimental procedure use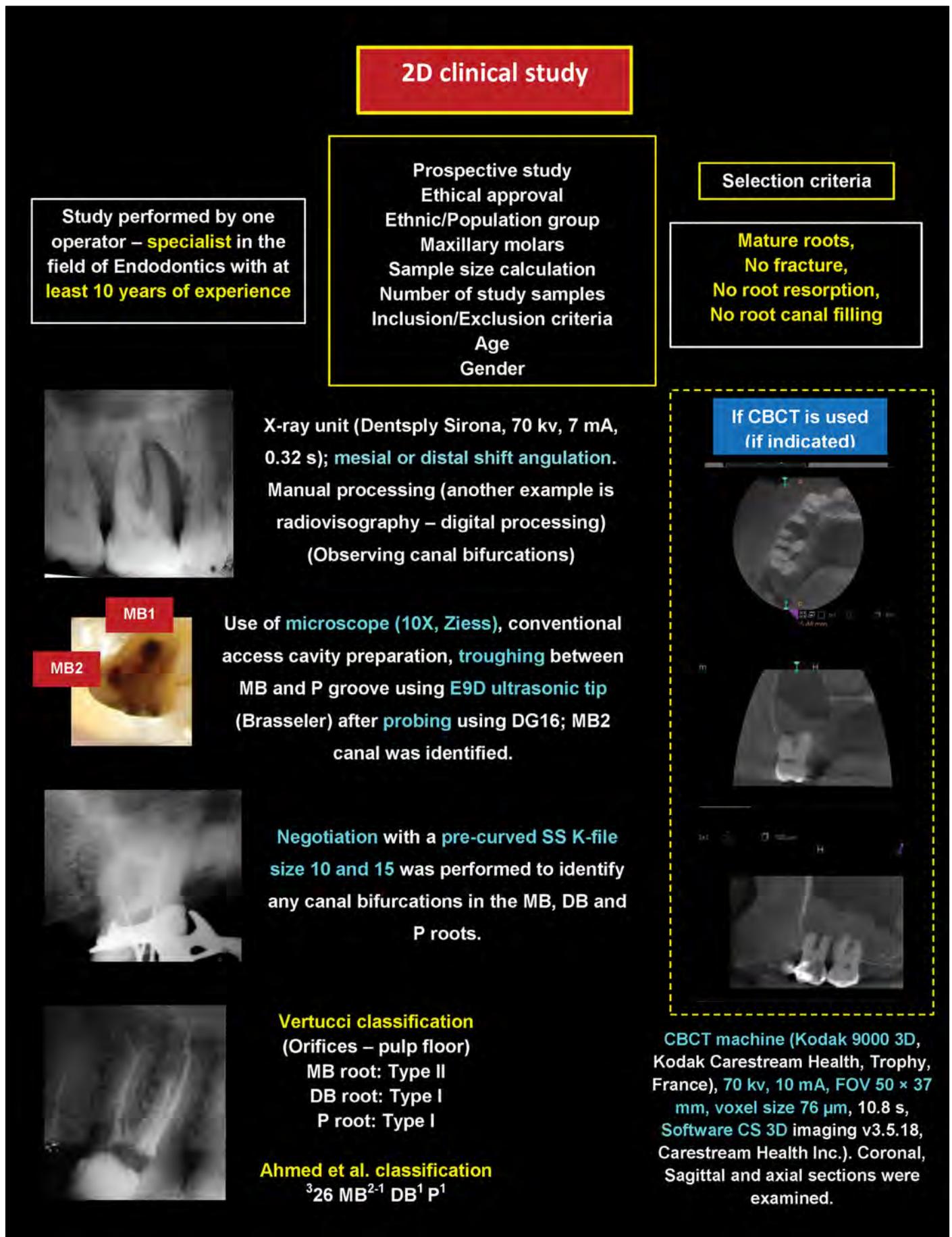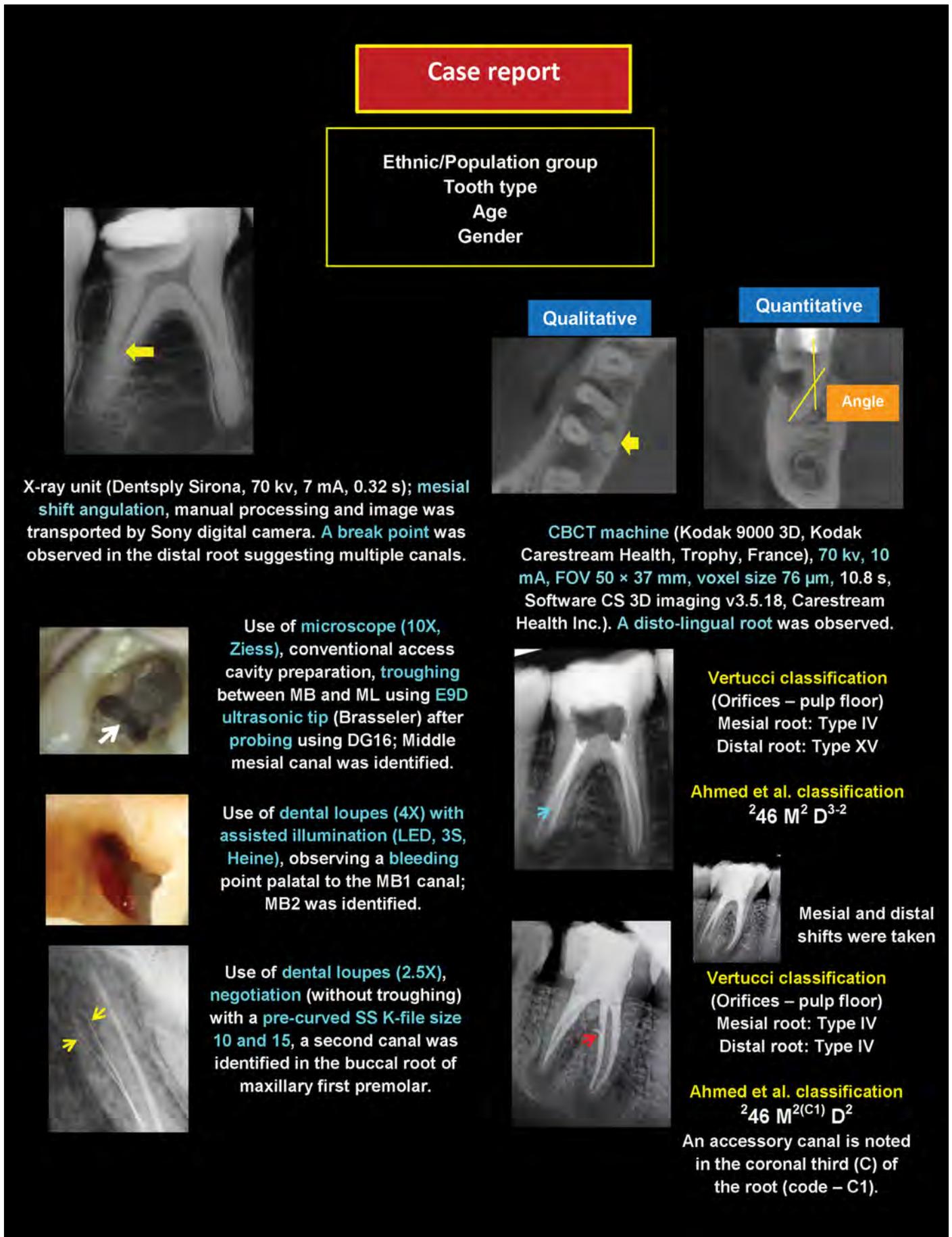d. The checklist protocol presented in this systematic review paves the way for a consistent description of root canal anatomy in experimental, clinical, and case report publications.

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PROUD GUIDELINES (2020)
Reporting Items for Root and Canal Anatomy in Research Studies

Section	Number	Checklist item	Listed on page number
Type of study	1	Experimental or clinical (cross-sectional or other); retrospective or prospective.	
Ethical approval	2	Approval from the ethical board committee.	
Ethnic group/population	3	Details on ethnic group or population	
Tooth type (or roots)	4	Tooth (teeth) type included in the study and/or roots.	
Sample size calculation	5	Information on how the sample size was calculated before undertaking the research.	
Number of teeth (and/or roots)	6	The number of study samples should be reported.	
Inclusion/Exclusion criteria	7	Information on how the teeth were selected – e.g. caries, resorption defects, restoration, root canal treated teeth, mature root apex, fractures, etc. Other factors related to imaging/processing issues such as artifacts or samples loss because of chemicals (such as staining and clearing) have to be mentioned as criteria for exclusion.	
Age	8	If applicable, the age range (or groups) of the study samples or patients should be reported.	
Gender	9	If applicable, the gender of study samples should be reported.	
Diagnostic device specifications and technique	10	<u>Radiographic machine:</u> This includes machine type, exposure settings Kv, mA, voxel size (if applicable), FOV (if applicable), angulation techniques, etc, as well as software programs used for analysis. <u>Other diagnostic tools (such as staining and clearing, SEM, etc):</u> The specifications and procedures should be mentioned in details. For all, calibration of the machine (if applicable) should be reported.	
Qualitative analysis	11	Such as root canal configurations, evaluation of root canal shapes.	
Quantitative analysis	12	Such as measuring volumes, areas, diameters, distances, angles.	
How the evaluation process was performed	13	Such as examining the coronal/axial/sagittal sections in 3D imaging, or observing the canal bifurcations in 2D imaging under magnification, etc.	
Endodontic procedures (if applicable)	14	Magnification, modification of the access cavity, exploration, negotiation with or without troughing and others applicable for 2D clinical studies).	
Classification used	15	Classification used for root canal configurations (with clear definition for orifice location and intracanal communications), root anomalies, accessory canals.	
Calibration and reproducibility	16	How the examiners were calibrated. Methods for calibration must be described clearly. Intra-rater and/or inter-rater reliability tests must be mentioned.	
Statistical analysis (if applicable)	17	The type of statistical method and software used for analysis should be reported.	

PROUD GUIDELINES (2020)
Reporting Items for Root and Canal Anatomy in Case Reports

Section	Number	Checklist item	Listed on page number
Type of report	1	Case report, Case series.	
Ethnic group/population	2	Details on ethnic group or population.	
Age*	3	The age of the patient(s) must be reported.	
Gender*	4	The gender of patient(s) must be reported.	
Tooth type	5	Tooth (teeth) type included in the report.	
Number of teeth included	6	Number of teeth included in the report.	
Diagnostic device specifications and technique	7	This includes machine type, exposure settings Kv, mA, voxel size (if applicable), FOV (if applicable), angulation techniques, etc. Software(s) used for the analysis.	
Qualitative analysis	8	Such as root canal configurations, evaluation of root canal shapes.	
Quantitative analysis	9	Such as measuring volumes, areas, diameters, distances, angles.	
How the evaluation process was performed	10	Such as examining the coronal/axial/sagittal sections in 3D imaging, or observing the canal bifurcations in 2D imaging under magnification, etc.	
Magnification	11	Operating microscope or dental loupes or other Magnification step, assisted illumination (if used) have to be mentioned.	
Modification of the access cavity	12	Conventional or changing the access cavity configuration to detect anatomy.	
Exploration	13	Such as DG16 or other explorers.	
Negotiation with or without troughing	14	Using ultrasonic tips or burs (troughing) or pre-curved files (without troughing).	
Other special clinical observations	15	Such as bleeding point, NaOCl bubbling, etc.	
Classification used	16	Classification for root canal configurations (with clear definitions for the orifice location and intercanal communications), root anomalies, accessory canals, etc.	

*In few occasions, case reports may have a presentation of both clinical case and extracted tooth – authors can mention "NA" if related information were not recorded for the extracted tooth.