Complementarity of OCT and radiography for imaging investigations in dentistry

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ABSTRACT

There are numerous dental conditions that can appear in the human mouth, from bone diseases like periodontitis or bone loss produced by a massive infection, to common issues like dental cavities. We explored the possible range of dental (and associated bone) conditions using Optical Coherence Tomography (OCT) versus the gold standard of radiological investigations [Erdelyi R.A., Duma V.-F., et al, Materials 13, 4825, 2020]. Clinical and imaging investigations have been performed on real-life patients. Advantages and limitations of using these two imaging techniques were deduced, based on the fact that OCT has better resolution than radiographs (2 to 10 µm versus 75 to 150 µm, respectively), while radiography can perform a complete image of the entire mouth, in contrast to OCT, which has a limited penetration, of only 1 to 2 mm in tooth or soft tissue. The analyses of a range of dental conditions with both techniques clarified when it is better to choose a specific method: (i) for bone diseases, radiographs are more appropriate because they provide images of the entire mouth in one exposure and 3D images of dental conditions; (ii) OCT can spot small cavities in early stages, while radiographs cannot; (iii) measurements performed on cavities spotted with both imaging techniques proved that OCT can provide accurate dimensions, with high contrast and contrast-to-noise ratio. Thus, a classification of each of the two types of imaging techniques for each possible dental condition was obtained. A complementarity of OCT and radiography for investigations in dentistry was concluded.

Keywords: Optical Coherence Tomography (OCT), dental medicine, radiography, dental conditions, 3D reconstructions, imaging methods, image contrast, biomedical photonics.

1. INTRODUCTION

Medicine benefits a lot from the technological development. Thus, Dentistry, as a division of Medicine, improved significantly in both diagnosis and treatment assessment of dental conditions. The most common techniques of medical imaging utilized in dentistry are based on X-ray radiation: two-dimensional (2D) radiographs (intraoral and panoramic) and three-dimensional (3D) Cone Beam Computed Tomography (CBCT). All of them are harmful for living tissue because X-rays belong to ionizing radiation.

OCT has been developed as a low coherence technique [1,2], initially for ophthalmology, where it became the gold standard [3], and then for skin [4-5], tympane [6], endoscopy [7], etc. Its area of interest has further expanded to Non-Destructive Testing (NDT), for industry [8,9], art [10,11], forensic science [12,13], etc. A field that may be the following

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one where OCT can become a must in Dentistry. Thus, there are early studies that demonstrated its use for this medical domain [14], and their number and impact has increased continuously [15-18]. We carried out a number of studies in this field, both for dental materials [19-21] and for investigations of hard and soft tissue in the oral cavity [22]. The present study, which is a follow up of the detailed one in [23], but also of several other works [24-26] has the aim to explore OCT capability to become such a major technique in common dental practice.

Also, this comes as a natural step in a direction of research in our groups that studies the capabilities of OCT versus the different gold standards of various domains, including: OCT versus SEM for metallic surfaces profilometry (for forensic investigations related to metal fractures) [12,13], OCT versus micro-CT for dental materials [22], OCT versus synchrotron microtomography and histology [27,28], etc.

Even though radiographs are considered the gold standard for medical imaging in dentistry, there are dental conditions that cannot be diagnosed, or treatments that cannot be assessed by any type of radiograph. For such cases, the aim of our studies has been to investigate if OCT can provide accurate images for diagnosis and treatment assessment. Certain advantages of OCT compared to X-rays techniques include: better resolution for OCT (of 2 to 10 µm for tissue), while for X-ray radiographs it is 75 to 150 µm (the former for optimized X-ray units); the capability to provide images of samples in a non-invasive way, without ionizing radiation. The question is how is should doctor choose the proper technique for a specific dental condition. The scope of this presentation is to present some of these results, presented in detail for other cases in [23], and to further demonstrate the fact that there is a complementarity between OCT and radiography.

2. MATERIALS AND METHODS

A working protocol was designed at the beginning of our studies in [23-26], by choosing the proper steps to obtain sets of images with both imaging techniques for each investigated sample (Fig. 1).

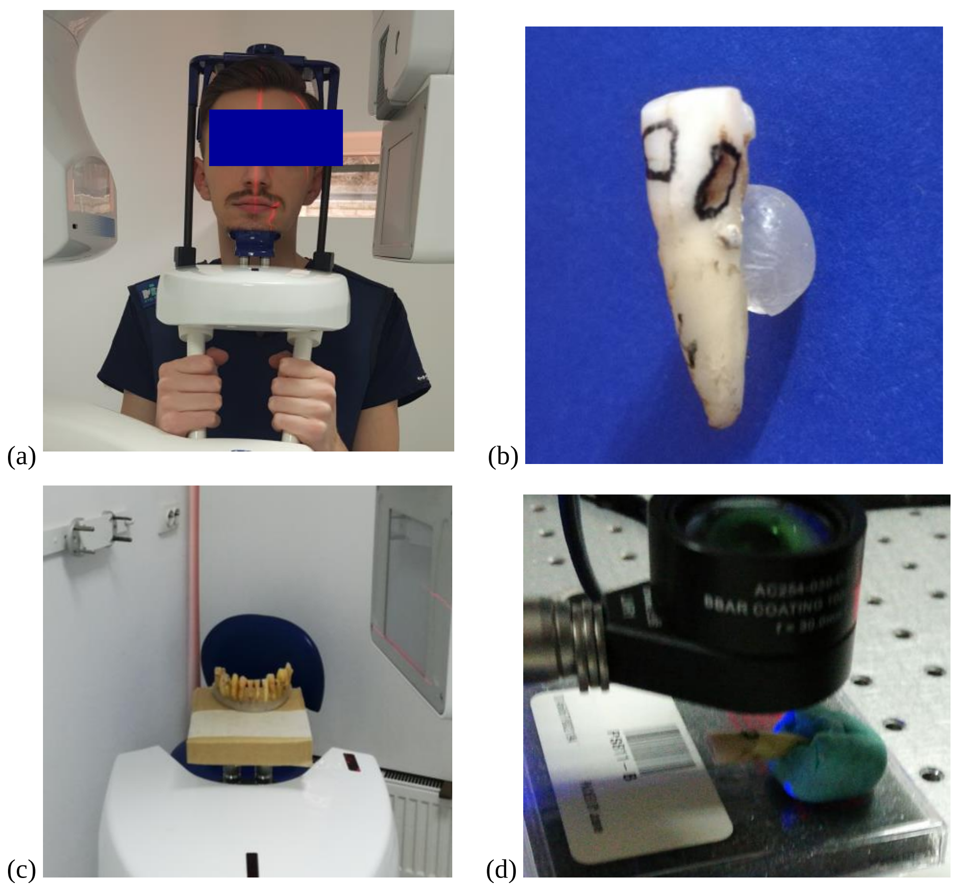


Figure 1. Steps from the protocol of the study: (a) X-rays diagnose; (b) tooth extraction and preparation for further investigations; (c) *ex-vivo* X-ray investigations; (d) OCT investigations.

First, the patient is diagnosed both clinically and radiologically. Also, in the same dental clinic *ex-vivo* radiographs are performed on extracted teeth.

These teeth were extracted due to their poor condition (large cavities, infections, periodontitis, etc.), cleaned and prepared for advanced investigations. After all radiographs were performed, both *in vivo* and *ex-vivo*, teeth were moved into the laboratory, at the "Aurel Vlaicu" University of Arad (UAV), where they were investigated with an in-house developed Swept Source (SS)-OCT system, Master-Slave (MS) enhanced [29]. Both images of the same sample (obtained with X-ray and OCT) were imported in the Romexis software (Planmeca, Helsinki, Finland) for further image analysis [30]. This software was utilized because it provides a calibration step and, therefore, there are no differences in measuring the different points of interest on the samples.

2.1 Samples

Images from both X-ray and OCT investigations were analyzed. *In vivo* radiographs were gathered from the Department of Radiology of the dental clinic. Patients came into the clinic for diagnose and treatment of dental conditions, therefore they were diagnosed both clinically and radiologically. Thus, for a consultation, the patient must perform a panoramic radiography and a 3D CBCT. Cases that needed tooth extraction (due to poor condition of the tooth that cannot be treated) were selected for this study. Nurses from the dental offices took the teeth after extractions and prepared them for *ex-vivo* investigations, cleaning the teeth by removing blood, gingiva, or even bone that came out during extraction.

(a)  (b) 

Figure 2. Example of a tooth during its preparation (a) and ready for *ex-vivo* investigations (b).

2.2 Radiographs

Two radiological units were used for both *ex-vivo* and *in vivo* investigations: Planmeca ProMax 3D Plus (Planmeca, Helsinki, Finland) for panoramic radiographs and 3D CBCT, as well as Gendex Oralix (Danaher Corporation, Washington DC, USA) for intraoral radiographs – Fig. 2. The capability of the X-ray units in terms of image characteristics are presented in Table 1.

There are differences in the details that can be made visible on radiographs. On one hand, for example, a cavity can be easily observed on an intraoral radiography, while on 3D CBCT cavities are not visible or images are not reliable. On the other hand, bone measurements can be correctly performed on 3D CBCT images, while on intraoral radiographs such measurements are impossible. The X-ray units must be optimized to provide high-quality images than are reliable for both diagnose and treatment assessment. All X-ray units from this dental clinic are working by strictly adhering to the *As Low As Reasonably Achievable (ALARA)* protocol [31]. This means that the X-ray unit performances must be as high as possible (in order to provide the best image possible), but with the lowest possible amount of radiation. Therefore, it is a trade-off between the maximum resolution and the maximum amount of ionizing radiation.

Table 1. Settings for Planmeca ProMax 3D Plus and Gendex Oralix.

	Intraoral Radiography	Panoramic Radiography	3D CBCT
Exposure time (s)	0.5 – 1	15	5
kV	68	72-73	90
mA	9	11	14
Radiation dose (μSv)	1	10	87
Pixel/voxel size (μm)	150	150	75
Area of interest	3-4 teeth	All mouth	11 cm diameter and 8 cm height 11 cm diameter and 5 cm height 8 cm diameter and 8 cm height 8 cm diameter and 5 cm height 5 cm diameter and 5 cm height

(a)

(b)

Figure 3. Example of several teeth prepared for (a) panoramic radiography and 3D CBCT and for (b) intraoral radiography.

The maximum amount of X-ray radiation allowed for a specialized worker with an X-ray installation is 20,000 μSv during a year [32]. As a single optimized 3D CBCT has 87 μSv, by corelating these numbers with the ALARA protocol, one might say that it is not necessary to optimize an X-ray unit as it is not easily to make a high radiation exposure even at the unit's highest performance. However, this is not true, for a number of reasons. First, and maybe the most important, a person may need other X-ray investigations, for other parts of the body. These radiographs come with a higher amount of radiation than dental radiographs. Second, during an entire treatment, the patient is exposed to several radiographies, and this increases the amount of X-ray radiation.

2.3 OCT

The idea of analyzing a sample with both X-ray and OCT techniques and to try to categorize the dental issues according to its suitable imaging technique came after performing a considerable amount of OCT investigations on dental samples. This led to summarizing how OCT can be utilized in dentistry, for a range of medical conditions. Thus, we gathered results from OCT studies that show the advantages of using this imaging technique. These were compared with results concerning dental conditions classified according to the capability of X-ray techniques to provide reliable information for diagnose and treatment assessment. Further on, we documented in [23] the rather simple conclusion that OCT and X-ray techniques are complementary.

OCT investigations have been performed on an in-house developed MS/SS-OCT system which was described in detail in [23] – Tab. 2. 500 B-scans are obtained during an OCT scan or the sample. These B-scans are further processed and analyzed with the open-source ImageJ processing software (Wayne Rasband, NIH/LOCI, University of Wisconsin) [33]. Thus, both 2D and 3D OCT images were obtained, just as in the case of panoramic/intraoral radiographs and 3D CBCT.

Figure 4 shows an example of a suitable B-scan selected from ImageJ and the 3D rendering of a tooth investigation. Teeth do not need preparations for OCT investigation, just as in the case of X-ray radiographs. Figure 5 presents a tooth with an area selected for OCT investigations.

Table 2. OCT system characteristics.

Item	Value
Laser source	50 kHz, swept in frequency Center wavelength of 1310 nm Sweeping range 1256.6-1362.8 nm
Area of investigation	5 x 5 mm
Axial resolution	10 μm
Penetration depth	1.5-2 mm
Maximum volume	5 x 5 x 2 mm

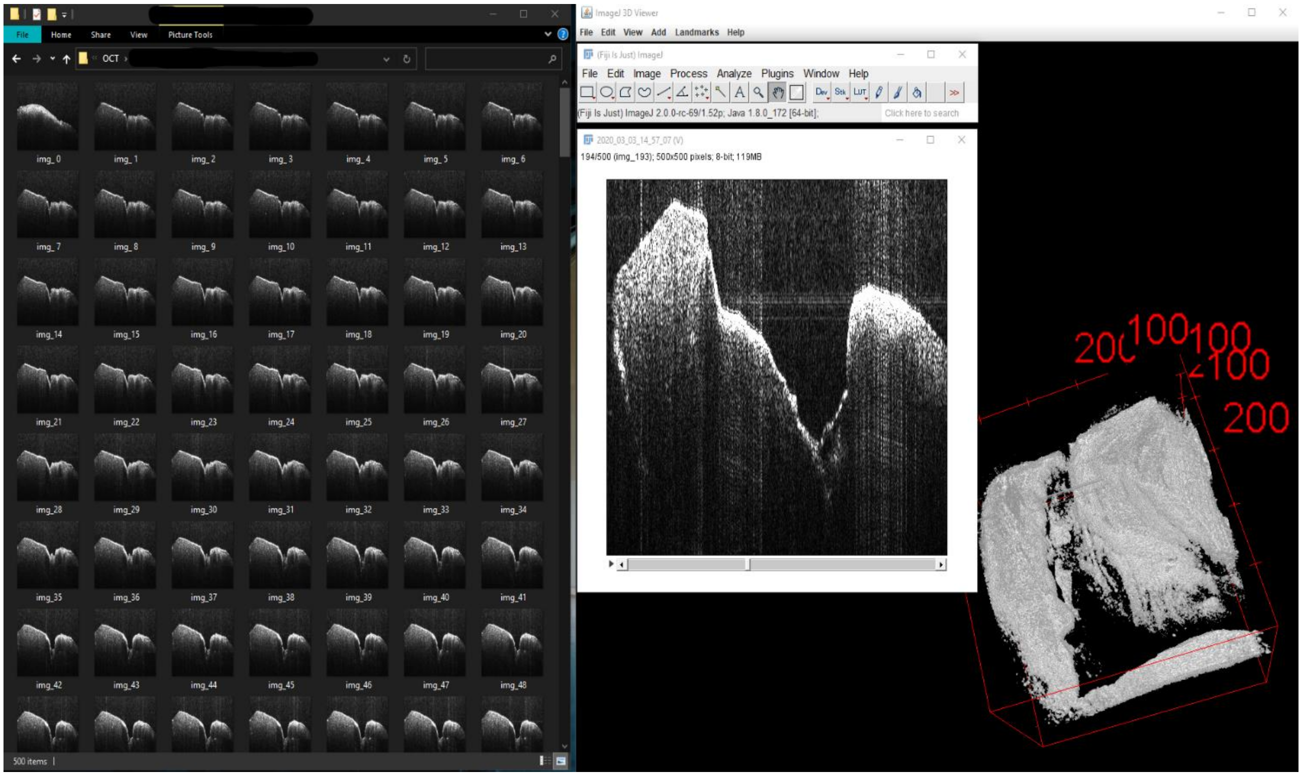


Figure 4. Image processing in ImageJ, 500 OCT B-scans and the 3D rendering of the 500 B-scans.

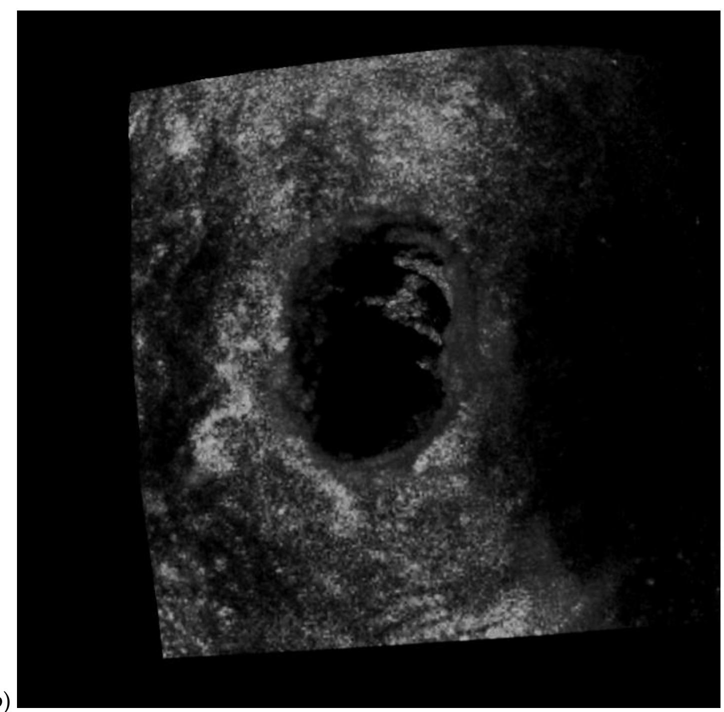
(a)  (b) 

Figure 5. (a) Surface of a tooth prepared for an OCT investigation. (b) OCT 3D reconstruction.

3. RESULTS AND DISCUSSION

The results can be grouped considering the suitable medical imaging technique for a specific dental condition. Thus, there are conditions that can be best investigated with X-ray and conditions for which OCT investigations are the most effective. Another differentiation between conditions (and corresponding clinical cases) can be made according to their purpose (diagnose or treatment assessment). Considering all these aspects, the following classification can be made [23]:

3.1 Cases suitable for X-ray investigations

Bone analysis and periodontitis can be included in the same category because periodontitis means bone loss. However, there are differences, because a correct bone analysis can be performed only on 3D CBCT, while periodontitis can be diagnosed only on a panoramic radiography. Several examples can be seen in our detailed work in [23]. Additionally, in Fig. 6 one can remark that 3D CBCT is more accurate for bone measurements, while panoramic radiography is enough to observe a bone loss without measuring it. In Figure 6, precise measurements of the bone can be performed using with the Romexis software on Axial and Sagittal views.

Table 3. Cases suitable for X-ray investigations.

Diagnose	Treatment assessment
Bone analysis	Implant positioning
Periodontitis	Bone augmentation
Teeth's roots analysis	Checking the place that remains after the tooth extraction
Full mouth analysis	Root canal treatment

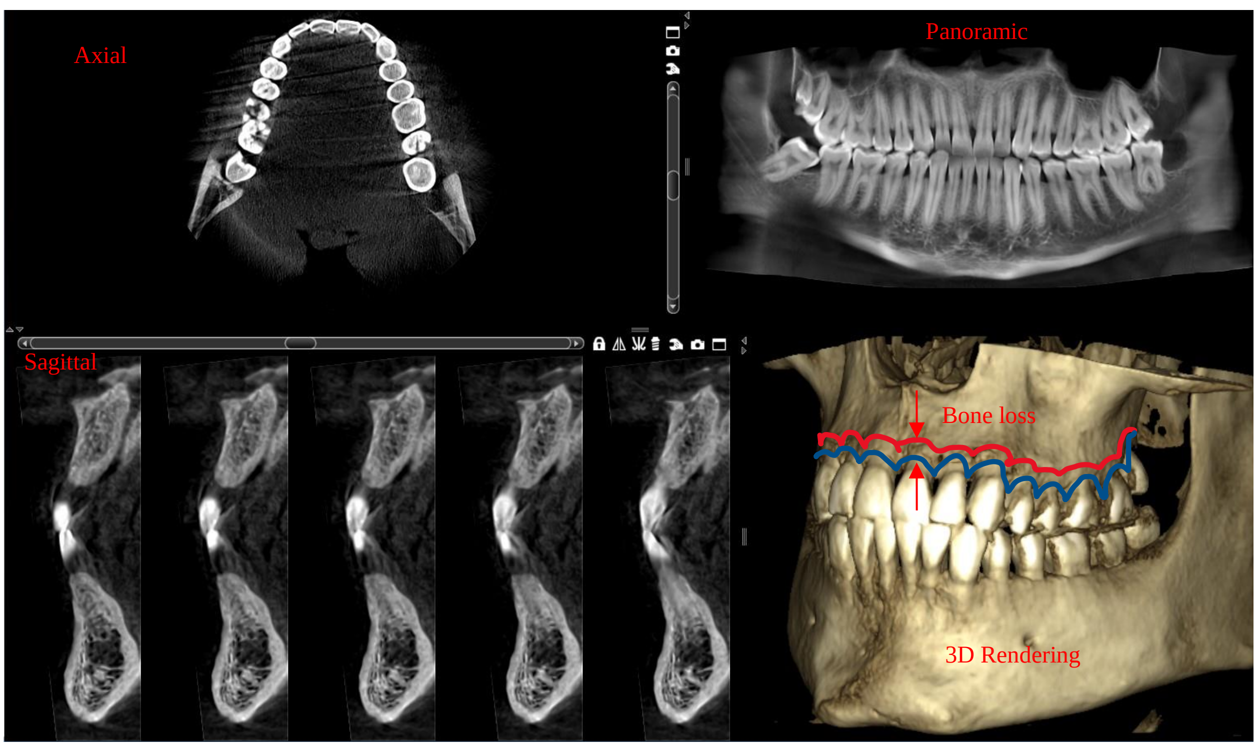


Figure 6. Imaging with different views using 3D CBCT.

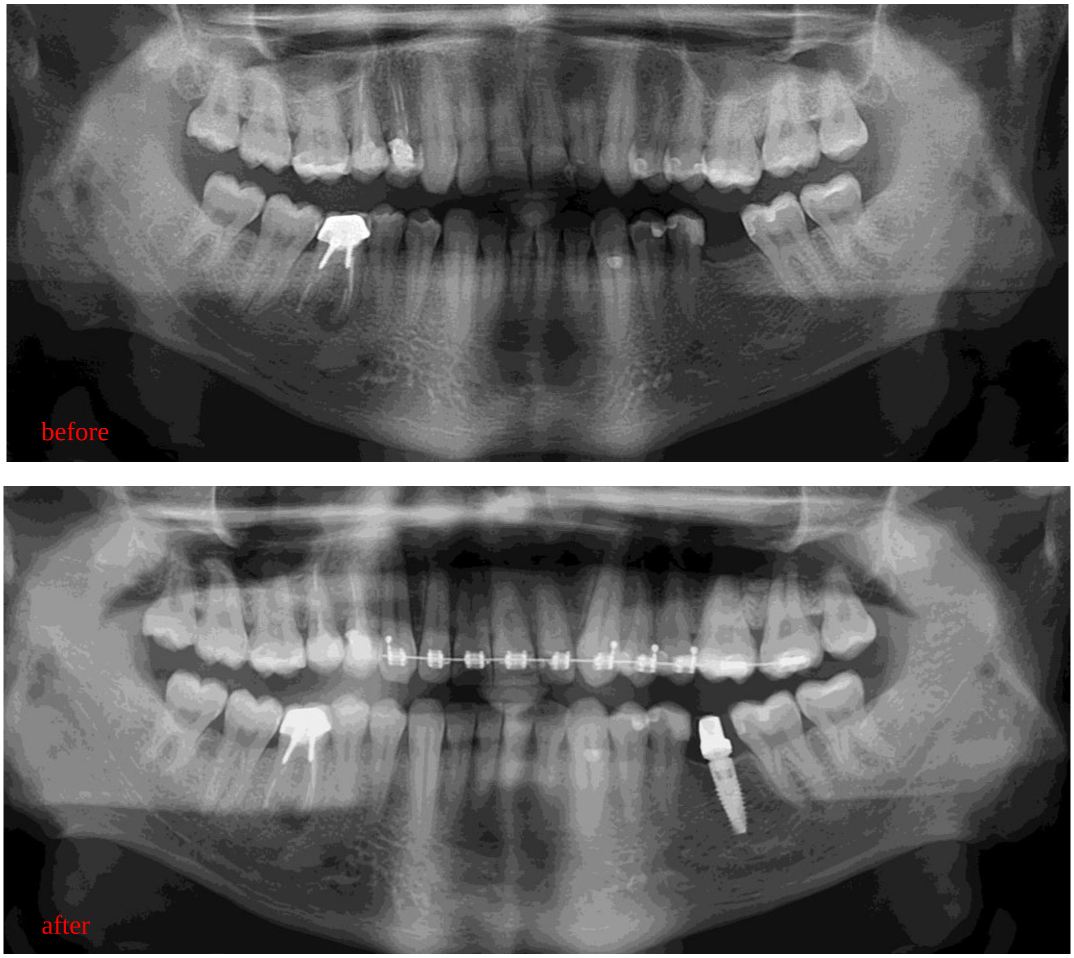
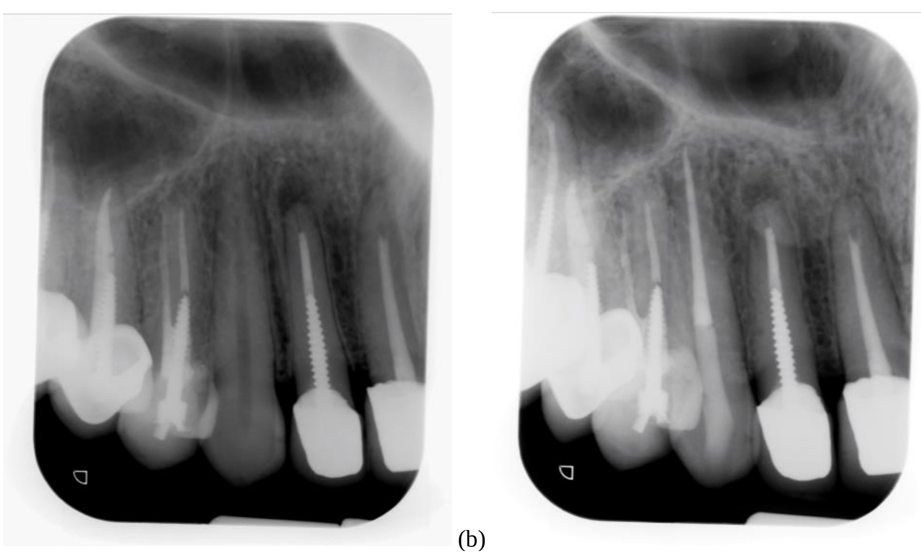


Figure 7. Panoramic radiographs before and after implant insertion surgery. On the panoramic radiograph performed after surgery, it can be seen that the implant is in an ideal position, at the middle of the distance between the neighboring teeth.



(a) (b)

Figure 8. Intraoral radiographs of a tooth before (a) and after (b) root canal treatment.

Panoramic and 3D rendering are exposing the bone loss of the patient who is suffering from periodontitis. Even though the patient did not lose any tooth, the periodontitis is present, and it must be treated from this early stage of the disease. Dental radiographs are today useful to create a surgical guide for dental implants. Such an operation is minimum invasive, and it offers a faster recovery for the patient. Dental technicians (i.e., the personnel who completes this surgical guide), import the 3D CBCT in their software and the doctor chose the position of the implant with the aid of 3D CBCT. Figure 7 presents a case where a surgical guide was used because of the narrow space due to teeth migration. This made the implant insertion surgery difficult. The advantage of using the surgical guide technique is the significant increase of the percent of a successful insertion of the implant because the surgical guide always gives the right direction during implant insertion [34].

Figure 8 presents the case of a root canal treatment which is assessed with high accuracy. In Figure 8(a) the canal is not obturated, while on Figure 8(b) the canal is sealed, and the treatment is performed correctly.

3.2 Cases suitable for OCT investigations

Table 4. Cases suitable for OCT investigations.

Diagnose	**Treatment assessment**
Cavities	Dental filling adaptation
Orthodontics	Orthodontics
Crown investigation	Crown adaptation
Enamel/dentine issue	Veneers investigations
Soft tissue	Soft tissue

OCT can be used in several situations for both diagnose and treatment assessment. Numerous examples we analyzed by us are presented in different works [23-26]. Thus, we demonstrated that cavities can be diagnosed with OCT and furthermore precisely measured on OCT images. The diagnose is more accurate than using X-ray images, with the remark that small cavities cannot be even spotted on X-ray images.

In addition to initial precise measurements, after the dental filling is performed the adaptation of this filling can be precisely assessed with OCT images [20,22]. Handheld scanning probes have been developed for OCT to perform such investigations [35,36], on an area of medical applications that includes dentistry [37,38]. In orthodontics, OCT can be useful for the analysis of enamel before and after orthodontic treatment. Some OCT investigations can be performed before to see the health of the enamel. Also, after the treatment is completed, the enamel damage can be observed on OCT images.

In another direction of work, crowns can be studied in dental laboratories with OCT with the purpose of finding defects that may appear during different types of fabrication [19]. In addition, crowns adaptation can also be correctly assessed with OCT technique. X-ray images are not reliable for metal crowns because artefacts may appear.

Enamel and dentine analysis can be performed only on OCT images. On radiographs the surface of the tooth and superficial cracks are not visible, while OCT can provide qualitative images in this case.

Figure 9 shows the level of the details seen on OCT images, which is clearly superior to radiographs. A radiography is useful to spot the areas that should be scanned using OCT.

Considered together, the X-ray techniques and OCT provide basically all the types of images required in dentistry, and all dental conditions are covered for both aspects, i.e., diagnose and treatment assessment.

While there are several aspects that are totally different in terms of image quality for both techniques (i.e., image resolution, penetration depth, field of view, and radiation safety), this diversity proves to be an advantage. Also, these complementary techniques can validate each other. For example, some “hot spots” can be spotted on a panoramic radiograph, to be furthermore studied with OCT. From examples exposed in this paper and in our previous studies [23-26], we can roughly say that OCT is more useful for analysis of surfaces and small dental issues, while radiographs are appropriate to investigate the entire mouth or areas that requires high penetration depth.

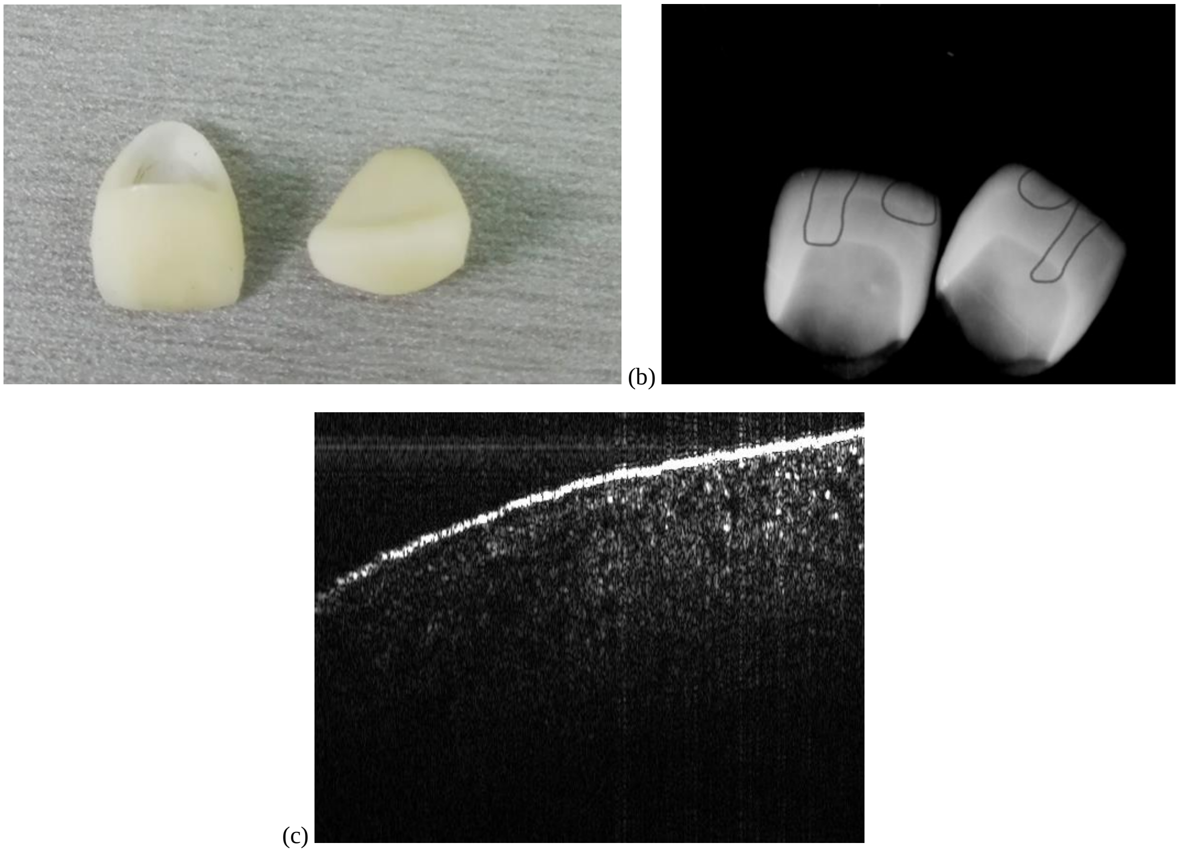


Figure 9. (a) Examples of zirconia dental crowns. (b) Radiographs of the zirconia dental crowns from (a). (c) OCT B-scan of a zirconia dental crown from (a).

4. CONCLUSION

According to specific dental conditions, radiography and OCT can provide qualitative images for both diagnose and treatment. Bone analysis, bone augmentation and implant insertion, apical infections, and root canal treatment are the most important dental cases that are suitable for X-ray technique. For conditions such as large or small cavities, enamel or dentine issues, analysis of crown or dental filling adaptation, and crown analysis, OCT proves to be more accurate than radiography (and is able to provide precise measurements even for small, incipient cavities), therefore OCT would be recommended to investigate such dental conditions. We are aware that radiography is the golden standard for imaging in dentistry and that an OCT system suppose additional cost to dental practice but the benefits that are involved by using such a system may well surpass the cost drawback. Thus, in a few years OCT systems may become a daily-basis imaging technique in dentistry, working together with X-ray units to provide required images for both diagnose and treatment assessment. A discussion on which technique is better to use is useless because both techniques have advantages and disadvantages, therefore choosing the right imaging technique for a specific case must be carefully considered [23]. Our future work in this direction involves covering different applications of OCT in dentistry and a comparison to results obtained with X-ray images.

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