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The digital patient – Imaging science in dentistry

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ABSTRACT

Dental imaging has seen a rapid technological advance over the last several years. Not only has most x-ray based diagnostic technology been digitized, with the possibility of low dose 3D computed tomography imaging, but many novel optical imaging techniques have now also been adopted in a more therapeutic imaging of the dental patient. When combining and manipulating such different digital image data, clinicians can now easily plan and simulate treatments on-screen, use 3D printed models and aids to assist in accurate transfer of the virtual planning or even follow-up their treatments over time. However, it seems that knowledge on digital technology is still lacking in clinical practice, which may contribute to errors or slow adoption. The purpose of this article is to bring an overview of the digitalization of dental imaging techniques and inform dental professionals on the digital tools that are available for the follow-up of patient treatments.

1. Introduction

The dental office workflow is rapidly evolving towards a more efficient and cost-effective chain using state-of-the-art technology [1,2]. Digitalisation of dental records, computer assisted imaging techniques and virtual treatment planning or simulations, have revolutionized clinical practice. Gradually, and almost consecutively, digitalization has been adopted in the three major steps of the conventional patient workflow, resulting in three distinct processes:

1) *Digital patient*: the acquisition of patient data is digitized (clinical information, x-ray based information or casts) and can now be stored or archived in the patient's digital records
2) *Virtual patient*: mental planning of the patient's rehabilitation can now be assisted with a digital treatment planning and on-screen simulation (computer-aided design or CAD).
3) *Real patient*: treatment procedures may be assisted with computer-aided manufactured (CAM) devices using milling or 3D printing technology

This digital treatment workflow can be applied to all fields of dentistry or dentomaxillofacial practice (see Fig. 1), but is most advanced in implant and restorative dentistry.

By the late nineties, virtual implant simulations based on Computed Tomography (CT) volumetric data had been introduced with the ability to create surgical templates for the placement of implants. The use of such 3D interactive planning environments have been found to help reduce treatment complications [3] by improving accuracy of placement. When using radiographic guides and visualising the prosthetic outcome, more advanced planning can be accomplished while transfer of this planned data to a CAM unit may generate surgical templates that can assist in a more precise implant insertion [4]. With the advent of low dose 3D Cone Beam Computed Tomography (CBCT), the 3D virtual planning of implant restorations has become widespread and by combining CBCT data with digital impressions, guided implant surgery has become an accurate and readily adopted tool [5].

In restorative dentistry digital impression-taking of preparations, has facilitated the design and production of restorations. With the introduction of many new CAM materials, laboratory procedures have become more efficient and immediate, same day, treatments have become more precise and widespread. The latter makes it more comfortable for the patient with a reduced number of visits, while it may even generate a more predictable aesthetic outcome [6–8].

Similarly, in orthodontic practice, virtual set-ups using digital models with on-screen simulation of orthodontic treatments have been found to be at least as accurate as conventional set-ups. In addition, such virtual planning may provide several advantages over the traditional approaches, for efficient storage, digital manipulation with reduction of manipulation errors and the ability to superimpose the stages of treatments at different time intervals [9]. Furthermore, transfer of the planning using guides and aligners, customized computer-manufactured appliances, guided piezo-assisted surgery, or even guided tooth transplantation may provide a more precise and predictable outcome [9–12].

More recently, the same digital workflow can be observed in the planning of complex endodontic cases. When creating a 3D model of a

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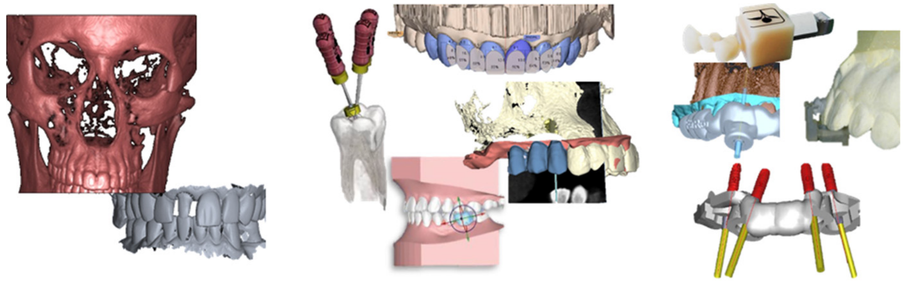

Fig. 1. Overview of the digital treatment workflow in dental implantology, restorative dentistry, endodontics and orthodontics.

desired tooth from the CBCT data, it is now possible to segment the canals and determine their curvature, and create a virtual simulation of the endodontic procedure by inserting digital files in the virtual set-up. This may prepare clinicians to better understand the complexity of the anatomy and avoid complications or even help in minimally invasive treatments [13–15]. Such approaches may also be of help in training and education programmes, providing consistent and replicable test cases.

Despite these advances many aspects of the digital workflow have not been thoroughly researched yet and improper use or understanding of the technology may lead to an accumulation of errors which may decrease these advantages over conventional techniques. From a clinical perspective, it is thus crucial to guarantee at least a similar precision in treatment outcome when adopting new techniques. For instance, when using novel x-ray based imaging, it is important to accomplish similar diagnostic results with at least similar but preferably reduced radiation doses. Digital impressions, say of a 3-unit bridge preparation, should have the same accuracy when compared to conventional elastomer materials.

What is obvious in the digital workflow of all above mentioned disciplines, is that digital planning is image based, which makes digital imaging a key aspect in the entire workflow. A thorough understanding of technology and the manipulation of such images may thus be crucial in the entire process.

2. Digital dental imaging

Imaging in theory is a mere representation of an object's form through visual images. In everyday life, electromagnetic waves with specific frequencies or energy levels have been adopted in this visualisation, especially non-ionizing radiation (see Fig. 2).

In healthcare, and especially dentistry, ionizing radiation is widely used when visualising the anatomical or pathological structures within a patient. This ionizing radiation uses x-rays that can damage healthy tissue and will transfer part of its energy to the subject, carrying, with each exposure, a risk to the patient. The ALARA (As Low As Reasonably Achievable) principle aims to ensure that only essential information should be obtained at the lowest radiation doses possible [16]. X-ray detector technology has evolved from conventional film based manipulations to digital 2D and 3D image hardware and software. The digitalization of intraoral radiographs has brought many advantages over conventional film, including lower doses, faster manipulation time, more efficient storage and image enhancement possibilities [16]. However, without proper knowledge of the technology and image manipulation parameters available, these advantages may not always be realised in clinical practice [17].

A recent survey of Belgian dentists revealed that most were not aware of doses associated with specific radiographic examinations [18]. These findings are common to other studies and this lack in knowledge of how and when to use such technology is even greater for the most recently introduced 3D imaging technology, dental CBCT [19]. While most studies reveal a lack of awareness in the dose of 3D CBCT, little is known if dental professionals are aware of exposure parameters like field-of-view (FOV), scan time, voxel size and tube current or voltage. These parameters all contribute to the radiation dose (and/or image quality) and thus allow a large exposure span within one specific machine [20]. For instance, a survey amongst endodontists in the United States, revealed that approximately one in five practitioners was not sure on the FOV they utilise [21]

Still, also and even more importantly for 3D CBCT, the ALARA principle should be respected and exposure parameters need to be adjusted to the clinical situation, both for the specific indication and individually for each patient. The many different parameters or variables have complicated the development of clinical guidelines, therefore certain basic principles should be adopted to ensure safe and effective use [22]. Unfortunately, much research is required to fine-tune exposure parameters in light of clinical image quality or detail in the 3D image versus its attributed dose. Furthermore, just as with 2D digital images, the use of dedicated image processing of 3D images may aid in diagnosis [23,24], but it seems only few clinicians are using these tools in everyday practice [25], while no studies can be found on their use on low dose exposure protocols. Finally, it seems also a prominent inter-observer variability may be present in CBCT diagnosis which clearly demonstrate the need for further education on this increasingly wide spread imaging technique [26,27].

Guidelines are crucial when it comes to x-ray based imaging, but strangely very few (or no) recommendations can be found for the use of non-ionizing radiation. For instance, many different fluorescence technologies are now available on the dental market but awareness may be lacking on their specific functioning and their indications. A multitude of research describes their advantages in diagnosis but their use is still restricted. For example, 45% of the surveyed Belgian dentists did not know what fluorescence was, while only 25% indicated the presence of such unit in their office [16,28]. Guidelines are lacking not only in diagnostic approaches, but also in therapeutic utilisation. Imaging applications like colour spectroscopy or digital impressions have now been introduced in clinics with significant differences between individual devices and providers [29,30].

The switch from conventional impression-taking to digital intraoral scanning (IOS) is a recent trend given the high precision and efficacy of modern compact scanning units. Many studies have already shown the numerous advantages of digital impressions over conventional techniques, including time saving, high patient as well as operator acceptance, reproducibility and precision [31–34]. However, in terms of accuracy, the literature provides contradictory reports. This is due to the definition of accuracy adopted by such studies and the numerous variables present in the digital workflow. Digital impressions may for instance be used in prosthodontics for CAD/CAM generated dental or implant restorations, or in implantology where they are fused with CBCT datasets for soft tissue visualisation and surgical guide creation, or in orthodontics where they can be used as study models or even for simulation of tooth movements for aligner fabrication. All these