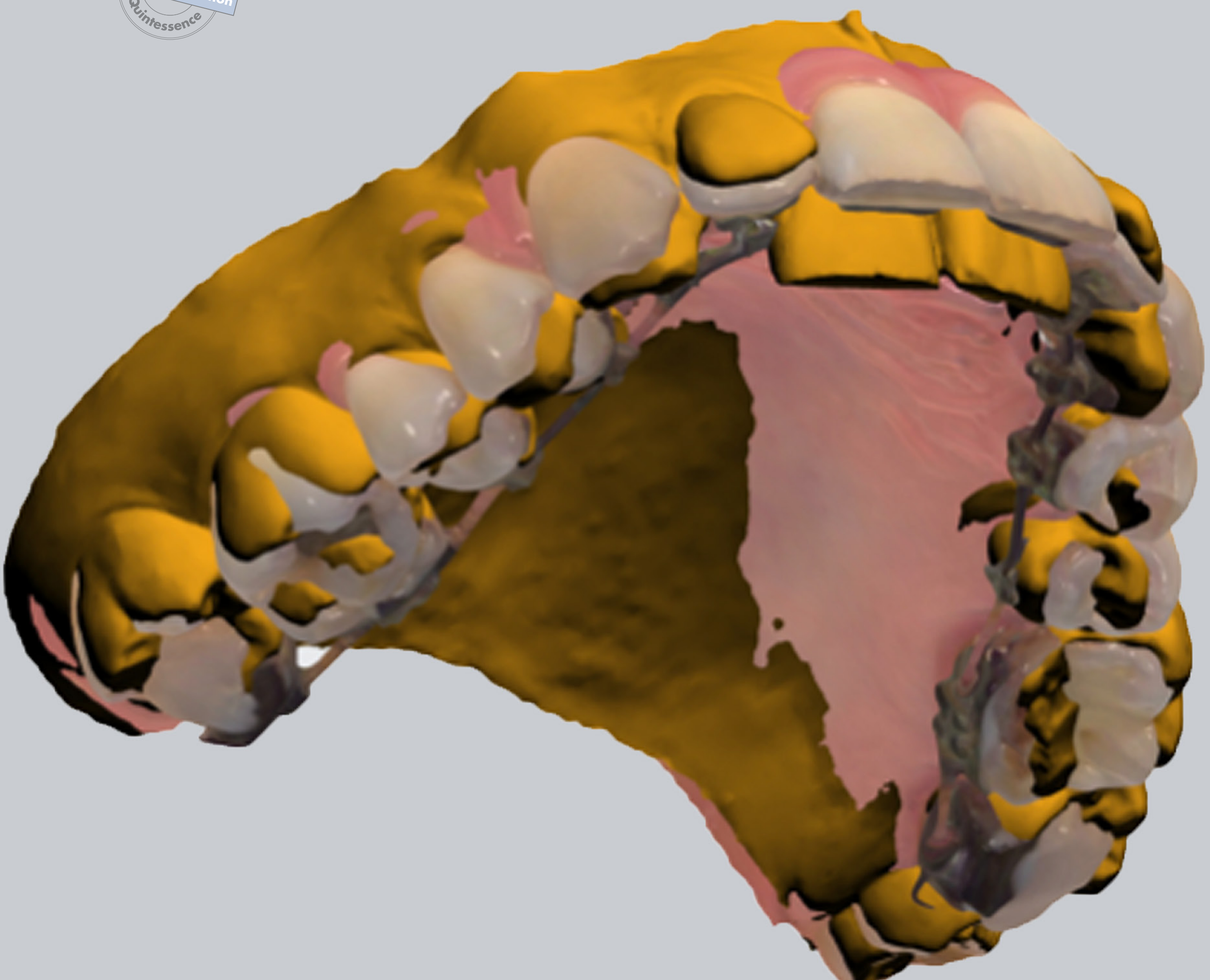
Timeline:
Using 3D Technology to Monitor Patients



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Monitoring patients is essential in modern dentistry. With adequate follow-up of some clinical conditions, the clinician is able to decide the most appropriate time for an intervention, to change a treatment approach, or to suggest the best treatment, and the monitored file can be kept as archived data. Tooth wear, height and volume of gingiva, tissue volume after surgical procedures, and tooth movement in orthodontics are some clinical scenarios in which monitoring can play an important role. For instance, measuring tooth wear is a key factor in selecting a suitable treatment in conditions of erosion, attrition, abrasion, or abfraction. Because wear is micrometric and there are no clear visual signs in the early stages, diagnosis and monitoring can be a challenge,[1] particularly if analog methods such as impressions or visual in situ measurements are employed. In periodontics and implant dentistry, detecting the gingival margin position is crucial to monitor recessions or to check the results of tissue augmentation or surgical recession coverage. Usually, these parameters are assessed with a periodontal probe, which presents accuracy of no less than 1-mm increments and is operator dependent.[2] In orthodontics, measuring teeth angulation and movements in buccolingual, mesiodistal, and apicocoronal directions assists the clinician in following the progress of treatment. Commonly, orthodontic progress is evaluated subjectively by clinical visual inspection and conventional photographs, or by means of measurements on stone casts. It is clear that monitoring the aforementioned clinical circumstances with traditional methods may result in lack of accuracy.

Intraoral scanners are becoming increasingly common in dental practice, presenting higher accuracy than conventional impressions for some clinical applications.[3,4] With recent advances in software analysis, the range of functions has increased.[5,6] Intraoral scanning and three-dimensional (3D) analysis allow patients' oral conditions to be easily recorded over time, making it a powerful alternative for patient monitoring. A series of scans are automatically aligned and superimposed, utilizing tooth morphology algorithms, and morphology differences between scans are subsequently quantified and visualized in a variety of ways.[7]

This article aims to present and discuss the potential use of a novel monitoring software tool to create intraoral scanning timelines that can be used to monitor patients for different clinical scenarios.

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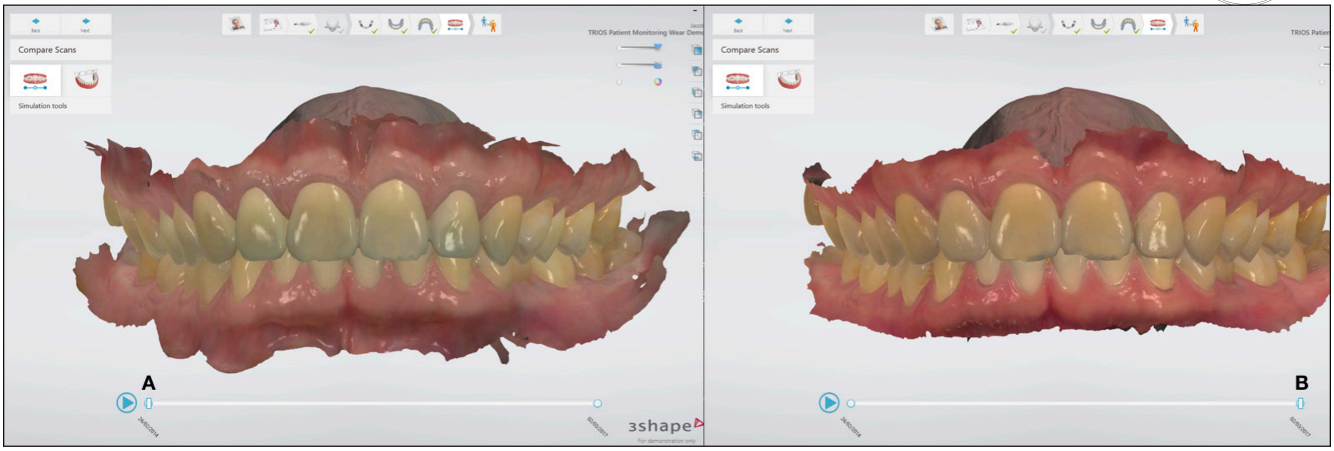


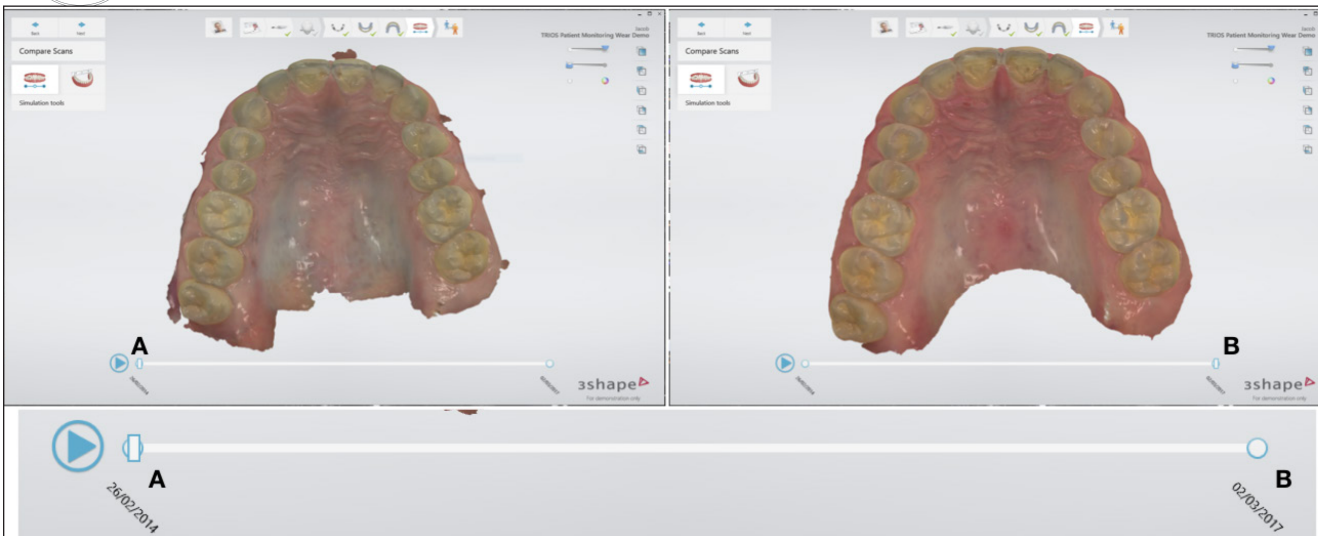
Fig 1 Monitoring tooth wear over 3 years: scan A, baseline; scan B, 3-year follow-up. Note the presence of chipped areas at the incisal edges of the central incisors.

TOOTH WEAR

Tooth wear is a common issue presenting multifactorial etiology, usually comprising effects of abrasion, attrition, erosion, and abfraction.[1,8] It shows increasing prevalence among different groups of patients, affecting up to 30% of young patients.[9] Tooth wear monitoring and management represent a clinical challenge in modern dentistry due to its considerably high prevalence and to the inherent difficulty of obtaining micrometric measurements. Most described indexes and monitoring methods also present a lack of consensus and difficulties in assessing long-term outcomes.[8] Furthermore, treatment may be complex, sometimes demanding oral rehabilitation with an increase of vertical dimension of occlusion.[1]

Besides defining risk assessments,[1] one of the most important strategies to determine an appropriate treatment approach in the management of tooth wear is its monitoring over time. Several methods for monitoring dimensional changes in tooth structure have been proposed. Quantitative methods rely on objective measurements on the affected areas, while qualitative methods rely on subjective description of the affected area based on indexes or visual graded scales.[8] Commonly used quantitative methods are direct photographs and measurements on stone casts,[10] despite noticeable lack of precision. Other approaches demand special equipment that is not familiar to the clinician, or even not available for intraoral use, eg, spectroradiometer,[11] optical coherence tomograph,[12] and pulse-echo ultrasound.[13] A profilometrical method had also been suggested, but this technique requires a metallic marker to be bonded to a specific tooth, and measurement is made on epoxy resin models obtained by conventional impressions.[14] Multiple steps, specialized equipment, and distortions caused by impression and pouring discourages such methods. A recent study proposed the use of scanned dental stone casts for monitoring tooth wear.[15] The initial results were consistent with other studies; however, limitations remain because the 3D scanning was dependent on the accuracy of conventional impression and pouring. Furthermore, third-party software was necessary to superimpose the images generated by the baseline and 1-year scans.

A fully 3D digital approach can offer a simple monitoring method for the clinician, also providing the best accuracy and precision in the wear measurements over time. 3D scans of the patient's dental arch are taken with an intraoral scanner (Trios, 3Shape) at baseline and at any subsequent appointment. Novel software-specific algorithms (Trios Monitoring, 3Shape) allow superimposing of the scans, resulting in an automatic and precise measurement of wear in any area of the desired tooth (Figs 1 to 6). In vivo wear of restorative materials can be also assessed using this technique, resulting in precise qualitative and quantitative data. 3D indirect methods based on scanning casts have been available for many years,[16] but direct measurement on the restorative material is innovative. Such methods may open a new era in the research of intraoral dental materials and occlusion.



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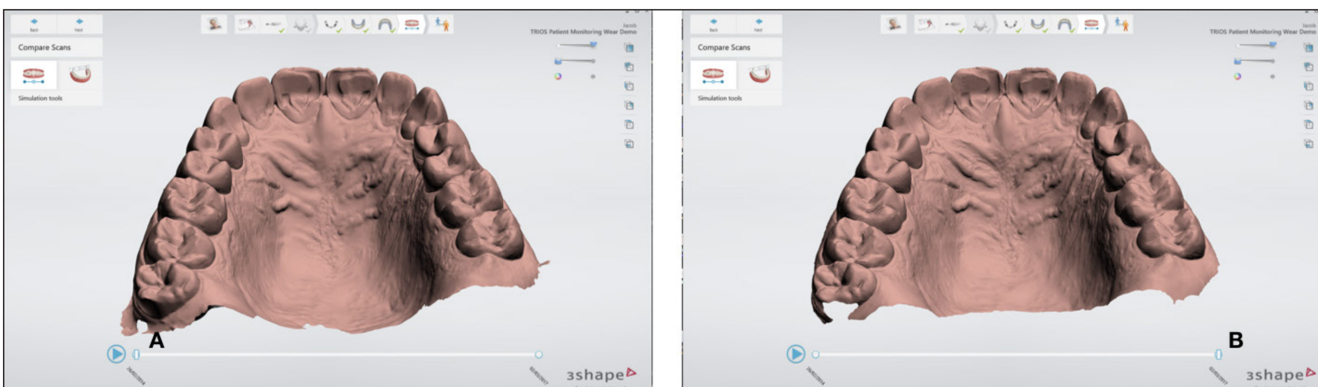

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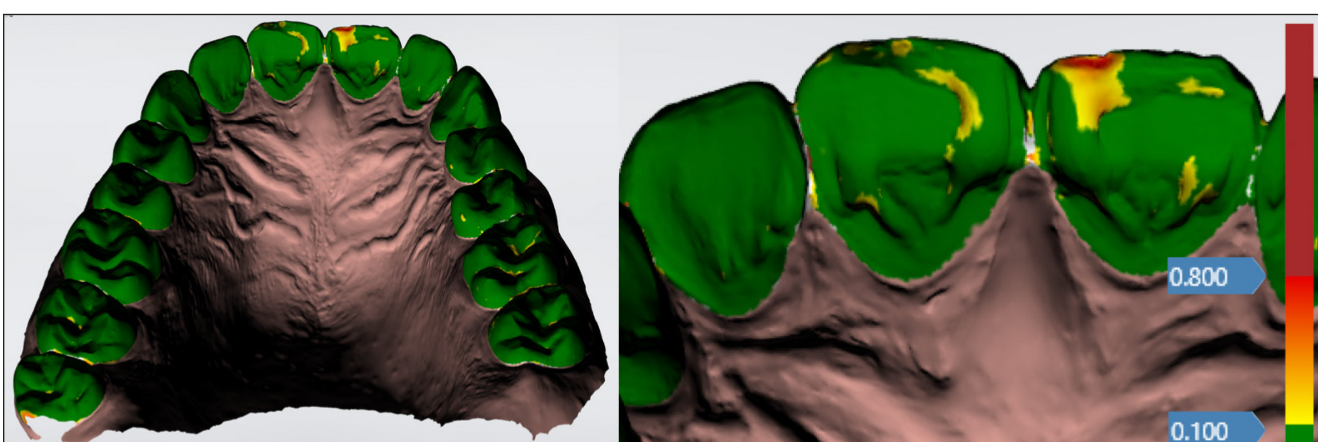

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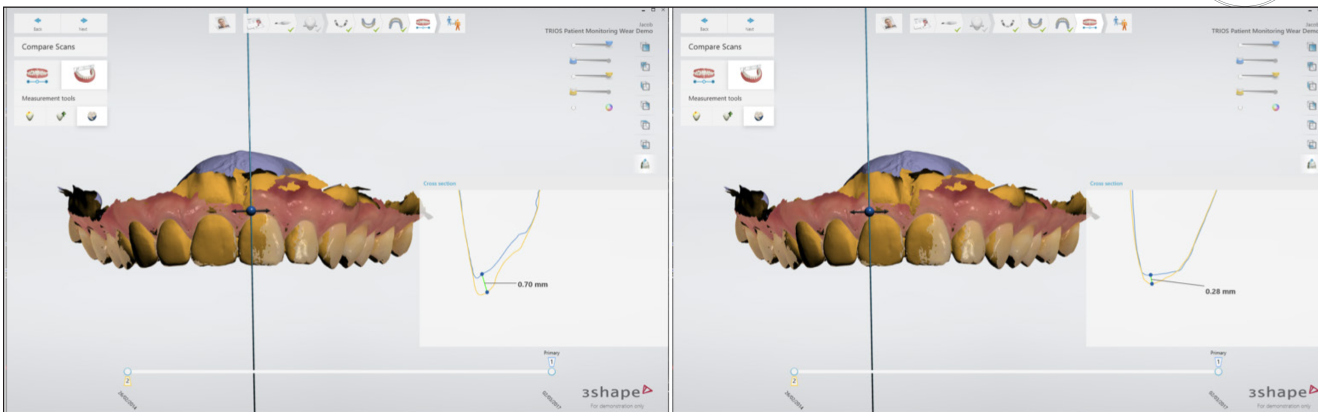
Fig 2 Palatal views of the scans with color.

Fig 3 Palatal views of the scans without color.

Fig 4 Scans A and B overlaid. Note the colored bar analyses showing the change observed on the palatal aspect of the central incisors after 3 years.



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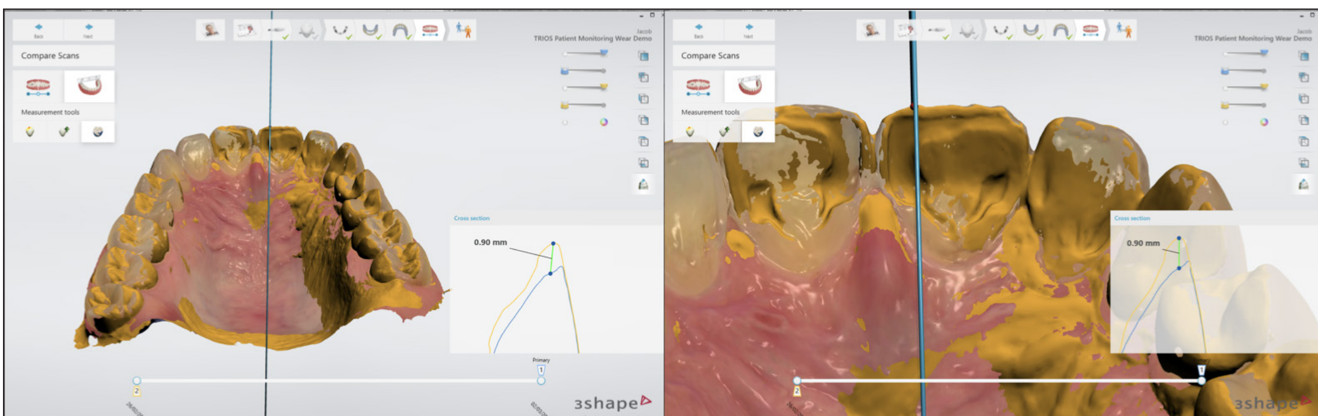

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Fig 5 Scans A and B showing the change observed at the chipped areas of the central incisors. The left central shows a loss of enamel structure of 0.70 mm, whereas the right central shows a structure loss of 0.28 mm.

Fig 6 Palatal aspect showing the severe condition of the left central, with 0.90 mm of enamel loss.

GINGIVAL TISSUE MONITORING

Gingival recession around teeth or implants may result in esthetic compromise. Recession can be indicative of periodontal or peri-implant disease, or other conditions such as toothbrush trauma, thin gingival phenotype, muscle pull, or teeth malposition.[7] The prevalence of gingival recession in the adult population is high, affecting almost 100% of individuals older than 35 years of age[17] (Fig 7). Identification and classification of gingival recession is necessary to predict the final outcome of surgical treatments.[18,19] Usually, diagnosis and treatment outcomes are evaluated by clinical examination using a periodontal probe,[7] which may eventually result in inaccurate records. Periodontal probes are graded with no less than 1-mm increments, so measurement accuracy may be affected. Furthermore, examiners must be calibrated. Digital calipers can be used to measure gingival recessions with better accuracy (0.01 mm),[20] but calibration of examiners is still necessary and in some intraoral areas it may be difficult to position the caliper points.

3D technology using superimposition of images obtained from scanned stone casts has been proposed for volumetric evaluation of gingival recession in vitro[2] and for tissue maintenance.[21] However, the inherent distortion of conventional impressions and pouring may result in errors, as can pressure on soft tissues caused by elastomeric material. Intraoral scanning has also been used to measure volumetric changes in the interdental papilla area; however, as an adjunct to the clinical step, a laboratory phase with the use of microcomputed tomography was necessary.[22] Cone beam computed tomography (CBCT) is a popular method with good precision to document dimensional changes in bone and soft tissues[23]; however, pa-

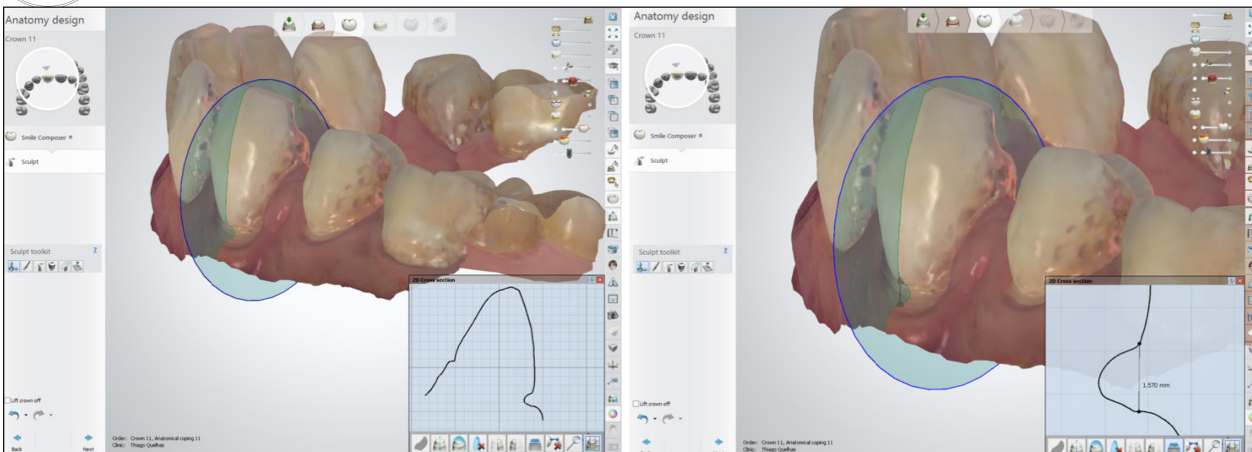

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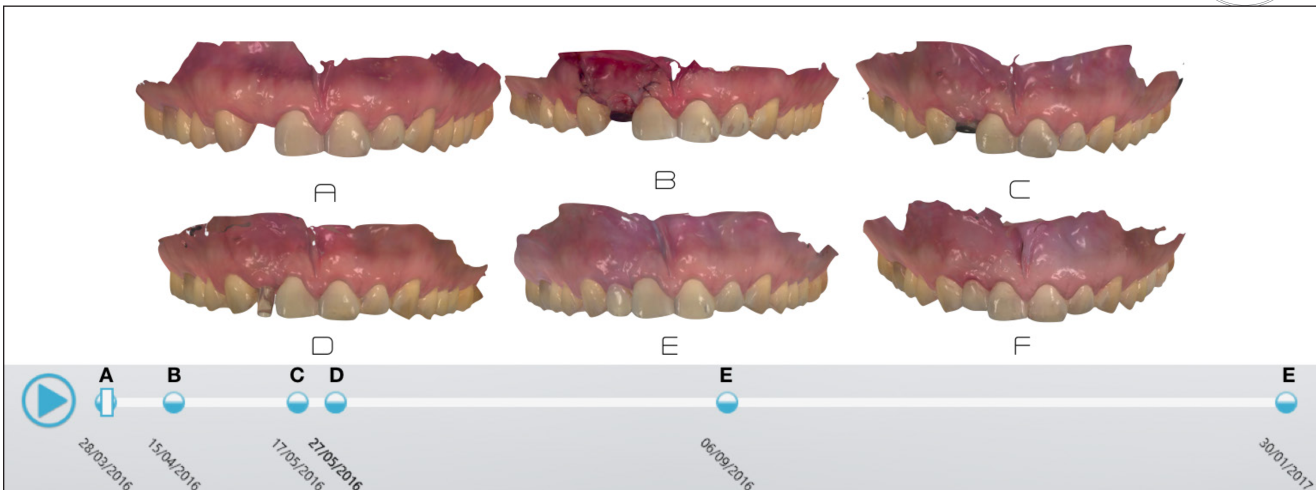
Fig 7 Measurement of a cervical lesion.

Fig 8 Example of scan of receded tissue taken at the patient's first visit. Measurement was obtained to evaluate recession for future monitoring analyses.

Fig 9 Maxillary image.

tients must be exposed to this x-ray exam at every step of the evaluation period. It appears that currently used methods may result in some inaccuracies or present technical difficulties.

The use of intraoral scanning with adequate superimposing algorithms allows a precise volumetric or linear quantitative evaluation. Data are provided that describe exact changes in the gingival margin, permitting monitoring and evaluation of surgical procedures (such as tissue and bone grafts) or techniques (such as immediate implant placement and provisionalization) (Figs 8 to 15). Patient education is also improved with the presentation of realistic 3D images. The presented method is particularly suitable for research—in clinical studies comparing volumetric covering of gingival recession using different surgical techniques or grafting materials, as well as in studies evaluating time of implant placement and provisionalization.



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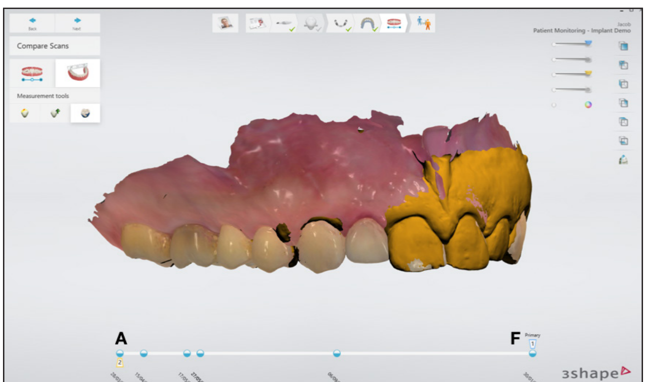

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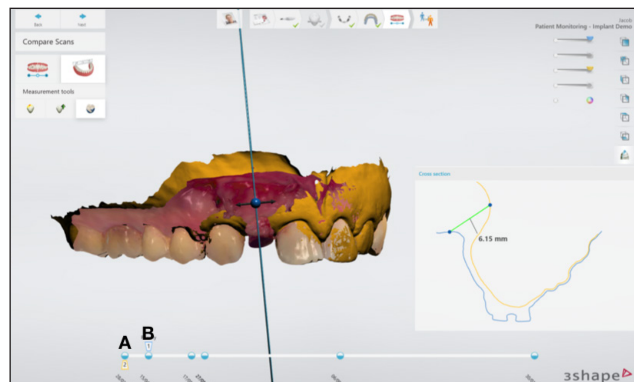

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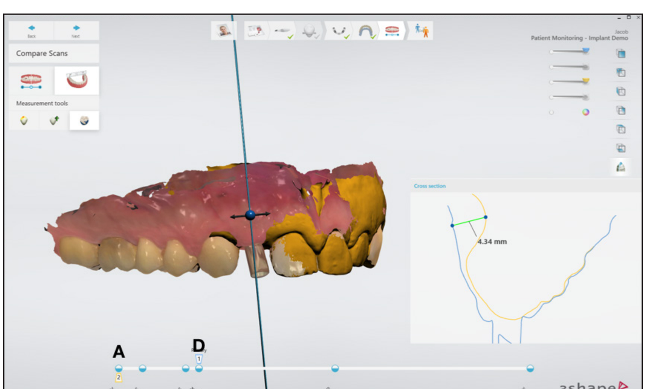

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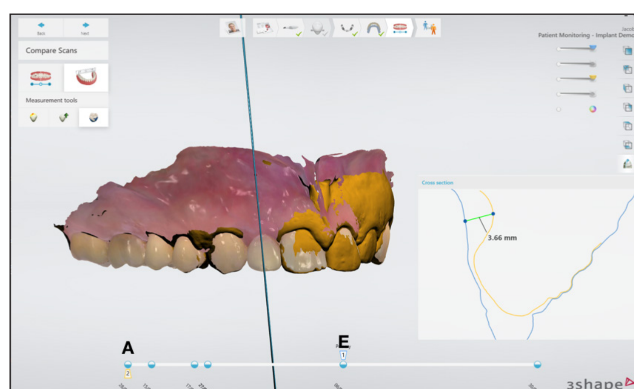

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Fig 10 Images of six performed scans. Note the timeline bar corresponding to the exact time of each scan: (A) starting point; (B) immediate postoperative; (C) 3 months postoperative; (D) scan body in place; (E) provisional restoration in place; (F) definitive restoration in place.

Fig 11 Image showing overlapped files. Scan F compared to the initial scan A.

Fig 12 Scan A (yellow aspect) and scan B (colored scan) being compared and measurement taken at surgical area of interest. Note the blue line representing the outline of the postoperative scan (scan B on the timeline bar) and the yellow line representing the initial aspect before surgery (scam A). Note measurement of 6.15 mm, the difference before and after the surgery (implant and grafting).

Fig 13 Comparative scans from baseline (A) and 60 days postoperative (D). After swelling is completely resolved, measurement was performed at the bone-grafted area (D, blue line), translating to a difference of 4.34 mm compared to A (yellow line).

Fig 14 Comparative scans from baseline (A) and 6 months postoperative (E). A change in bone measurement from 4.34 mm to 3.66 mm is noted.

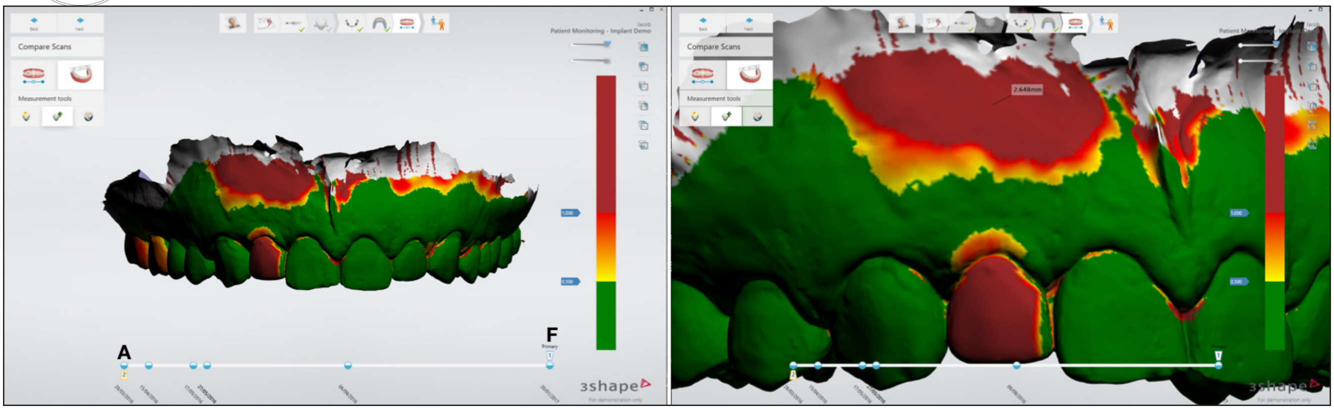


Fig 15 Case evaluated and quantified using colored bars. Comparison between baseline A and F (1 year after surgery).

ORTHODONTIC TRACKING

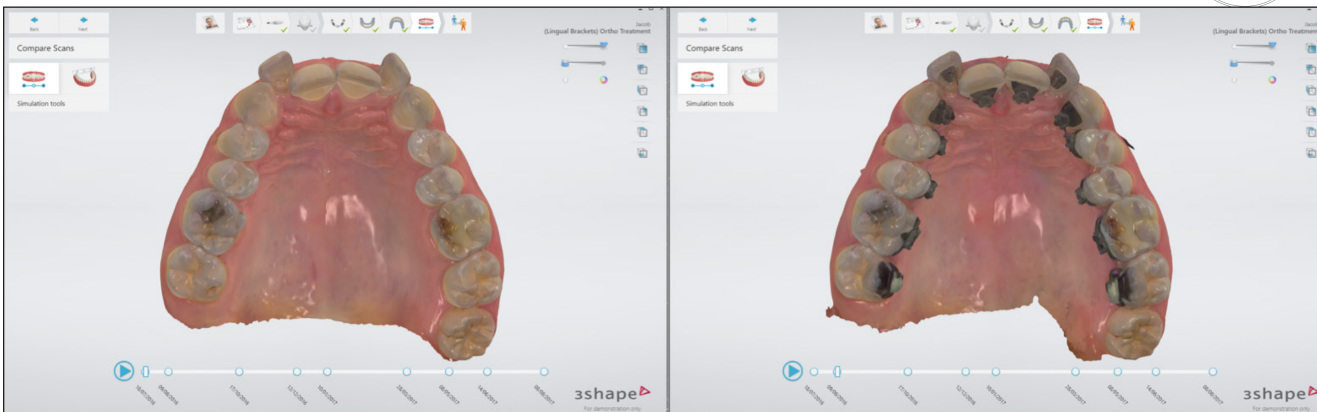
The progress of orthodontic treatment is usually assessed by clinical visual inspections, photographs, radiographs, and intraoral or stone cast measurements of teeth displacements with calipers.[24] These are the methods currently used by clinicians to track their treatments, being accurate enough for determining whether to alter the mechanics, change applied forces, or continue with the original planning. In some situations, however, it can be difficult for the orthodontist to perceive whether tooth movement is adequate using these conventional techniques.

The analysis of 3D superimposed intraoral scans of various treatment phases brings accuracy to orthodontic tracking. Real measurements of teeth displacement and angulation provide safety in decision-making during any phase of the treatment. Compared to conventional impression taking, pouring, and photographing, it requires less time and offers more comfort for the patient.[25] Also, 3D intraoral images of orthodontic movements are helpful for patient education as well as for legal issues. Further development will allow merging of CBCT data with intraoral scans, permitting complete analysis of bone, teeth, soft tissues, and facial changes over time.

3D technology has been used for the analysis of outcomes of orthodontic treatment in a study in which bone, teeth, and facial soft tissue variations before and after treatment were reconstructed by CBCT and 3D photography.[26] Despite the innovative technique, tracking during the active phase of orthodontic treatment was not recorded; to do so, CBCTs would have been needed to have been taken at each analysis. **[Au: Is editing of this paragraph OK?]**

More recently, several techniques have been proposed to accelerate orthodontic treatment, such as corticotomies, corticotomies with piezoincision, low-level laser therapy, photobiomodulation, vibration, interseptal bone reduction, and pulsed electromagnetic field.[27] Most of the studies presented efficacy of the proposed techniques based on intraoral measurements with probes or calipers with or stone cast measurements. 3D digital intraoral measurements of tooth displacement using the presented technique will bring more accuracy to studies evaluating these adjunct acceleration techniques.

An orthodontic case documented with nine intraoral scans that were performed over a period of approximately 1 year is presented in Figs 16 to 18. With this procedure, occlusion analyses can be made as treatment evolves, resulting in greater patient motivation and better orthodontic decision-making.



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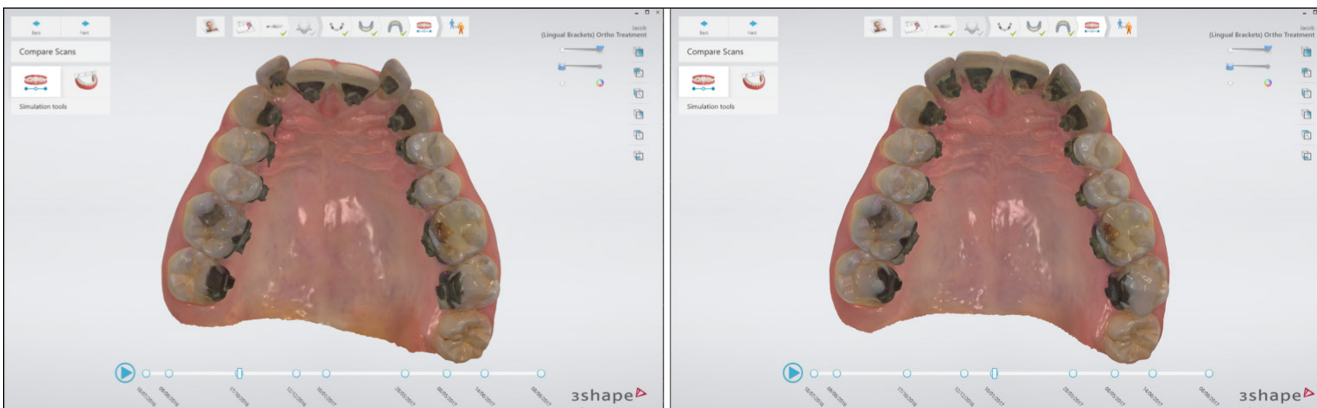

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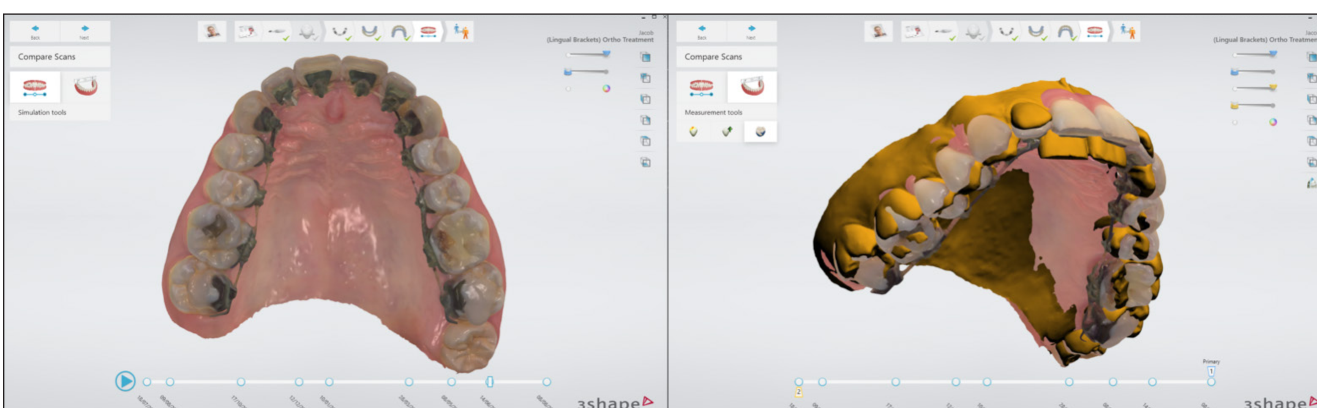

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Fig 16 Orthodontic follow-up with scans during approximately 1 year of treatment. Shown are baseline with and without the lingual braces in place.

Fig 17 Orthodontic treatment in its intermediate stage. Note the difference in tooth positioning in the two images.

Fig 18 Final treatment obtained *(left)* and image presenting the initial treatment condition (yellow scan) and the final outcome (colored scan). The colors are used to differentiate the scans.

CONCLUSION

Increasingly, digital 3D dentistry is exceeding the initial concept of CAD/CAM-produced restorations. Intraoral scanning may be used to record clinical images in a safe, easy, comfortable, and noninvasive way at various time periods. Novel software algorithms are able to precisely superimpose 3D images, calculating dimensional or linear changes and displacements. The potential of the monitoring tool is enormous, encompassing the diagnosis and monitoring of several clinical situations. Measurement of tooth wear in parafunctional patients, detecting the amount of tooth movement during orthodontic treatment, or monitoring stability of gingival healing after an immediate implant provisionalization are examples of potential applications of the presented technology. It brings to the clinician an objective and accurate modality to monitor their patients. Moreover, presenting easy-to-understand 3D scan images may encourage and motivate patients to accept a treatment or clinical recommendations. As a precise and nondestructive quantitative tool to measure dimensional changes in vivo, it can also be used to assess wear of restorative materials, to verify the amount of soft tissue gained after different augmentation techniques, or to assess the efficacy of an orthodontic appliance, among other potential applications.

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