Present and the future of digital orthodontics☆

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Digital technology had significant impact into our life since the introduction and sophistication of mobile phones. Medical diagnosis, teaching tools, treatment modalities and surgical technics were improved significantly with the help of digital technology during the last two decades. Digital technology started to make its way into dental and orthodontic offices with the introduction of computerized scheduling in the 1974. Today digital technology has touched on every aspect of orthodontic treatment. It is now common place to perform virtual treatment planning as well as translate the plans into treatment execution with digitally driven appliance manufacture and placement using various CAD/CAM techniques from printed models, indirect bonding trays and custom made brackets to robotically bent wires. Furthermore it is also becoming possible to remotely monitor treatment and control it. (Semin Orthod 2018; 24:376–385) ***© 2018 Elsevier Inc. All rights reserved.***

Introduction

Most significant impact of digital technology into our life was most probably the introduction and sophistication of mobile phones. Then digital invasion was exponential and boomed very quickly with the introduction of iPhone, Apple technology, social media, drones and Telstra. Who would have imagined that a car could drive around without a driver, would recognise the street signs and its functions can be controlled from your mobile phone. Huge improvements in medical diagnosis, teaching tools, treatment modalities and surgical technics were introduced during the last two decades. Digital technology started to make its way into dental and orthodontic offices with the introduction of computerized scheduling in the 1974. Since then and over the last three decades most offices have now become paperless and digital photography and radiography have replaced their analogue counterparts and become the mainstay. Intraoral scans and three dimensional radiography are rapidly replacing study casts and two dimensional radiography. Today digital technology has touched on every aspect of orthodontic treatment and not only records collection and keeping. It is now common place to perform virtual treatment planning as well as translate the plans into treatment execution with digitally driven appliance manufacture and placement using various CAD/CAM techniques from printed models, indirect bonding trays and custom made brackets to robotically bent wires. Furthermore it is also becoming possible to remotely monitor treatment and control it (Figs. 1−10).

The digitization of orthodontic diagnosis and treatment planning

Intra oral scanners have now largely replaced impressions and study casts. The scans are considered as accurate if not more accurate than plaster models. The scanning process is more comfortable for patients especially with the reduced gag reflex. They are easily stored and also shared with any dental laboratory anywhere in the world through the internet without the need for the packing and sending impressions. This also eliminates two possible sources of error and material variability in the impression taking and handling and pouring and manipulation of

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☆Digital age is here and has a significant impact on all aspects of our life.

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Figure 1. Tesla electric car and a drone.

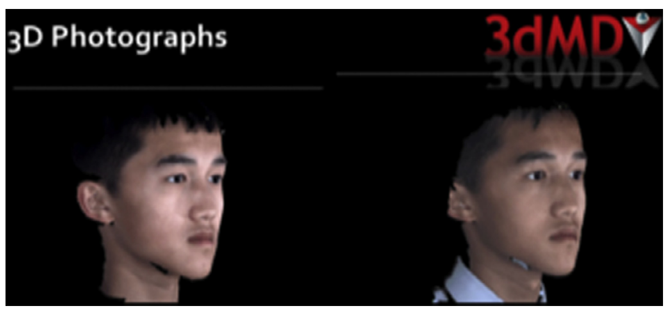

Figure 2. An example of 3D photography using 3dMD Kodak Photography Unit and software.

Figure 3. Superimposition of initial and final CBCT images using Anatomage software.

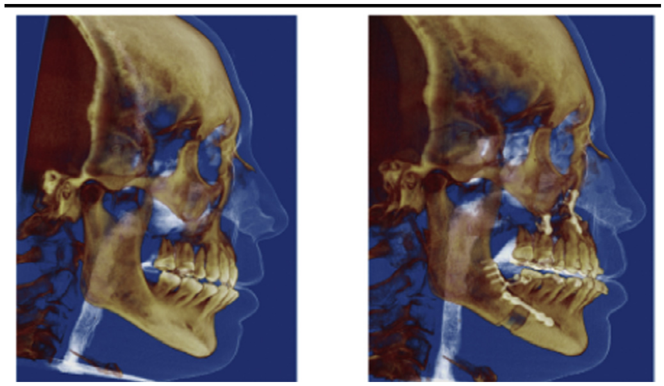

Figure 4. Initial and post-surgical CBCT Images morphing hard and soft tissues.

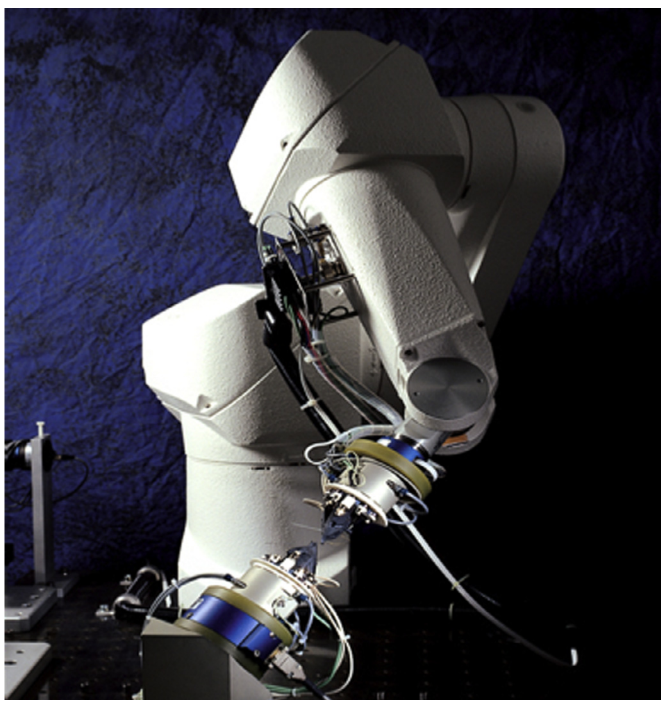

Figure 5. SureSmile® system (Orametrix, Richardson TX) wire bending robot

plaster casts. The digital files can be sent to the lab, which can print them into a physical model or use them for direct digital appliance design and manufacture. Additionally the models are immediately available chairside for analysis and viewing. It is then faster and more accurate to undergo study model analysis and accurately calculate things like Bolton's tooth size discrepancy in a speedy and more precise manner when compared to plaster models.[1] Furthermore the models can also be used in various orthodontic software platforms to allow the orthodontist to perform virtual treatment plans and explore various treatment plans within minutes as opposed to expensive and time consuming diagnostic setups and wax-ups. Performing digital setups not only allows the clinician to explore a number of treatment options in a simple manner it also facilitates better communication with other dental professional especially in cases that require combined orthodontic and restorative treatment. The virtual treatment planning also allows for better communication with patients and allows them to visualize the treatment outcome and also understand the treatment process.

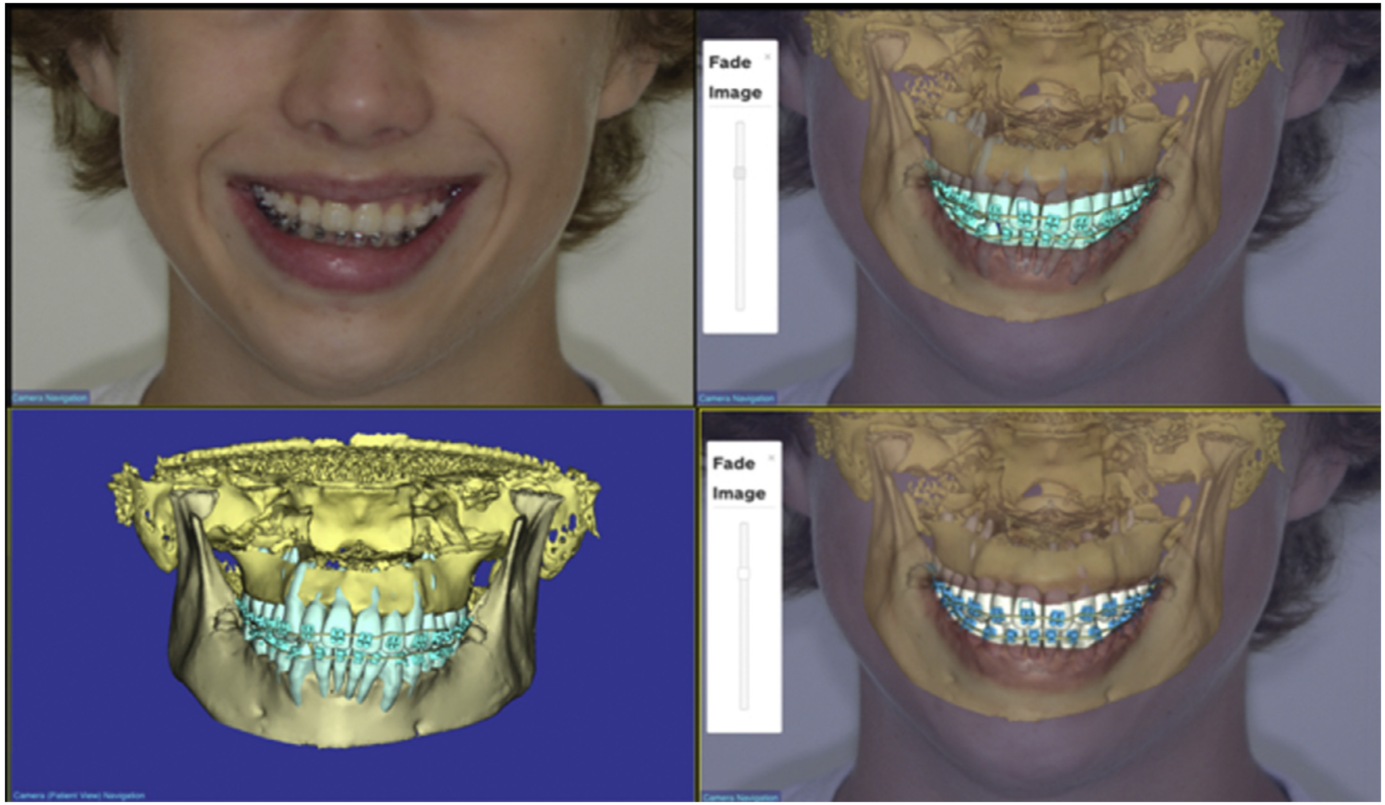

Figure 6. merging. of the Facial smile photos, Intra oral scan and CBCT data to create a model that can simulate treatment ourcomes and mechanics. SureSmile® system (Orametrix, Richardson TX).

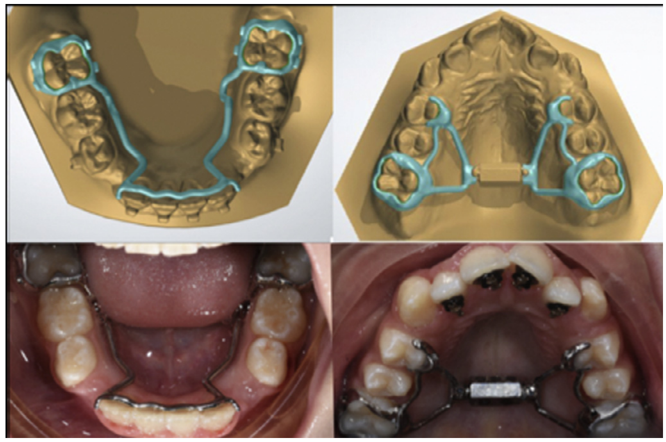

Figure 7. Direct 3D metal printed maxillary expander on casts and after bonding.

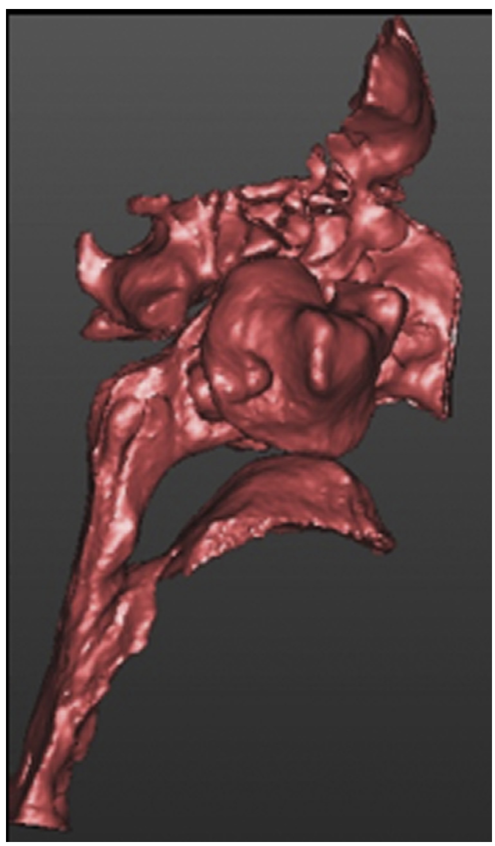

Figure 8. 3D image of the airway obtained from CBCT data.

Three dimensional radiography in the form of CBCT is also gradually replacing conventional two dimensional radiography especially as the radiation doses from these scans are getting lower. The advantages of CBCTs in diagnosis cannot be over emphasized especially in cases with eruption problems, TMJ issues, complex orthognathic surgery cases, to locate and diagnose maxillo-facial pathologic structures, root proximities, root resorption and impacted teeth.

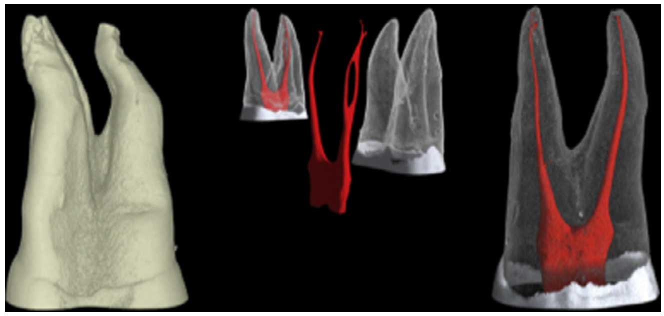

Figure 9. Colour coded images of extracted premolars using Micro CT Imaging data showing the pulp chamber and the pulp canal.

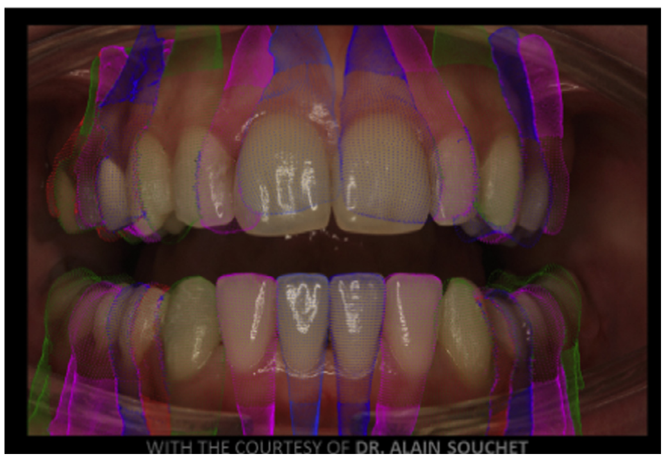

Figure 10. Dental Monitoring software analysing tooth movement using artificial intelligence (courtesy of Dr. Alain Souchet).

The ability to rapidly and accurately assess the tooth and bone position and condition in all three dimensions is invaluable for accurate diagnosis and treatment planning.

By introducing 3D facial photography to digital study models and CBCTs it is now possible to have a complete three dimensional virtual representation of the patient. Various software platforms are now available that combine the intraoral scan with hard tissue data CBCT scans and 3D facial photographs. Furthermore it is also possible to add function with mandibular movements and smile to have a full representation of the orthodontic patient.

The digital nature of these records allows easy and fast collaboration between various practitioners and laboratories. In addition the virtual models can be used to simulate various treatment effects, facial changes in real time and perform a host of linear and volumetric measurements.

The virtual treatment planning comes at a great advantage for surgical cases[2] where it is not only possible to diagnose more accurate but also allows the visualization of bony and soft tissue changes.[3] This can then be translated into the manufacturing and direct printing of surgical splints for precise surgical results.[4] Furthermore the surgical fixation plates and drill guides can be directly printed leading to unprecedented levels of surgical precision.[5]

The same technology can be used to increase success with mini screws and temporary anchorage devices. The success of TADs for example is highly dependent among other things on the quality of bone at the site of insertion. Combining intraoral scans and CBCT data enables the production of implant insertion guides using CAD/CAM technology to insure placement of the TADs in the best possible locations.[6] Furthermore TAD supported appliances can be manufactured in advance using the same models so that the TADs and the appliances be placed at the same appointment greatly reducing chair time while increasing the precision and efficiency for the operator and the patient.

Digitization of appliance manufacture

CAD/CAM technology has been around dentistry for over three decades and has made its way into orthodontics through the printing of models for aligner therapy, the direct printing of brackets Incognito® system (3M-Unitek, Monrovia, Calif) and robotic wire bending SureSmile® system (Orametrix, Richardson, TX).

Clear aligner therapy with Invisalign® introduced by Align Technology lead the way in using a virtual model, creating a virtual setup of the desired outcome and manufacturing appliances from digital models to deliver the pre-set treatment outcomes. The placement of attachments for control of tooth movement, the need for interproximal reduction and or extractions and the planning for inter arch mechanics is all done in advance. This process allows the visualization of the tooth movement process and allows the operator to visualize their treatment mechanics and for the patient to review the outcome before starting treatment. At this stage however aligners are still moulded on individual printed models of every step in the sequence but it is to be expected that direct printing of aligners with biocompatible material will be introduced in the very near future.

The digital appliance manufacturing has also changed fixed appliance therapy. It started with lingual appliances over 15 years ago when Dr. Wiechmann[7] combined virtual set-ups, customized bracket printing and robotic wire bending to create a fully customized lingual appliance. A virtual set-up is created with the desired treatment outcome and then fully customized brackets are digitally designed to conform as closely as possible to the lingual surface of the teeth and are then 3D printed in wax and then cast in gold. This enabled the creation of a lingual appliance with a low profile that closely mimics the lingual tooth surfaces with reduced discomfort for the tongue. While the wires were then robotically bent to match the individual lingual arch form to achieve the desired outcome. The result is a fully customized appliance with a high degree of precision[8] and reduced discomfort.

This technology has also been utilized for labial appliances with the introduction of Insignia[9] by ORMCO (Ormco, Glendora, CA, USA) as a system of customized labial appliances which are then indirectly bonded.

Although most orthodontists utilize a form of the straight wire appliance precision wire bending is required especially in the finishing stages of treatment. This can be time consuming and can take significant chair time. SureSmile has provided a digital platform that allows intraoral scanning with fixed appliances in place.[10] The models are then used to create the desired finish and the wires are then robotically bent to great precision to achieve the desired result. The advantage of the system is that is allows for any brand or type of fixed appliances to be used. In addition CBCT data can be merged to give accurate root positioning and to enable working within the bony envelope of the individual patient. The incorporation of the facial photographs allows the smile design to be done in 3D. Studies have shown that this utilization of technology can reduce treatment times with fixed appliances by up to 35%.[11,12]

Aside from customized bracket manufacturing digital technology now also allows virtual bracket position and the constructions of indirect bonding trays.[13,14] One company even allows the simulation of the outcome when a virtual straight wire is inserted thus allowing the correction of bracket positioning errors and more ideal appliance placement. Indirect bonding trays are then directly printed and brackets simply placed into the positioning jigs for accurate transfer into the planned position. Indirect bonding with this method is thought to increase bracket positioning accuracy and thus reduce overall treatment times.

Direct appliance manufacturing

The direct printing of non-metallic appliance became possible as soon as 3D printing with biocompatible resins became possible. Removable appliances can now be directly manufactured without the need for plaster casts.[15] But until recently commonly used banded metallic appliances such as the Hyrax, lingual arch, transpalatal arch and the Herbst appliance required the placement of separators and then the fitting of bands and analogue impression. Recently the direct printing of metallic appliances has become a reality using laser meting technology. Graf et al.[16] introduced the use of LASER melting to produce maxillary expansion appliances, which are virtually designed and then directly printed using CAD/Cam technology. This allows for traditional metallic banded appliances to be manufactured without the need for the traditional steps of separation, band fitting and analogue impressions. The appliances are manufactured and ready for direct placement without the production of any models. There are a number of advantages; firstly it eliminates the discomfort associated with separation and impression taking secondly there is the chair time saving. Additionally the virtual appliance design allows great flexibility in appliance design with very precise fitting.

Orthodontic research: It comes as no surprise that the digital technology has significantly impacted orthodontic research. For decades the assessment of clinical treatment outcomes relied on the comparison of pre and post treatment two dimensional cephalograms or the manual measurement of changes on plaster casts. The recent introduction of 3D superimposition techniques of study models as well CBCTs/CT[17] scans has enabled unprecedented insights into the effects of orthodontics, orthopaedics and orthognathic surgery not only on the teeth and surrounding bones but also on the facial soft tissues and airways.[18] It is almost certain this will become the standard for evaluating treatment outcomes in the very near future as radiation doses are reduced. Furthermore finite element models can be constructed with a great degree of accuracy to closely mimic the real world effects enabling better modelling of biomechanics for orthodontic tooth movement and orthopaedic treatments.

On a microscopic level the use of microCT allows much closer view of bone and root changes. The 3D visualization and measurement of volumetric changes and resorption craters is giving a better understand of tissue changes with orthodontic treatment.[19,20] It is likely that clinical CBCTs and scanner will gradually increase their resolution and will decrease the radiation level and the information currently only obtainable for a high radiation microCT will become available with regular clinical scanners. This will make root canal treatments (RCT) easier in terms of checking the shape of the root canal as well as cleaning and filling it up and finally checking the success of the RCT.

Compliance monitoring

Compliance with orthodontic treatment regimens especially those that involve the patient wearing a removable appliance or elastics have always been a challenge.[21] Studies have also shown that patients may perceive their compliance to better than is actually is. Poor or low compliance can slow down orthodontic treatment or lead to failure. It is particular important when the reporting the results of a study on compliance dependant treatment as the data become significantly distorted by the compliance factor. The incorporation of digital monitoring devices into appliances has revealed patient's report of compliance is certainly different to reality.[22] There is also some evidence that if a monitoring device is inserted in the appliance compliance may improve. Such digital monitors have great potential not only in monitoring treatment and motivating patients but in insuring consistency in research findings. It is also possible that these devices will be able to allow the patients to connect to apps on smart phones to see their treatment progress and perhaps orthodontists will be able to receive live feedback for the patients' progress form their appliances and forces may be modified accordingly.

A very innovative approach by an Italian group SuperPowerMe[23] is the customization and the gamification of facemask wear. In addition to 3D printed customized facemask for increased comfort, by incorporating sensors into the appliance not only allows us to measure compliance but also to link up with a smart device application that turns to a computer game. The child can only play the game and reach certain points while wearing the facemask. This not only encourages compliance but makes wearing the facemask more fun and entertaining.

Remote monitoring

In today's busy world people are relying more on more on online shopping and accessing everything remotely. Dental Monitoring (Dental Monitoring SAS Paris, France) is taking this to orthodontics in a way. Using the app patients can take regular progress scans with a smart phone of their teeth and face and through the company communicate their progress to the managing orthodontist. In this way patients are not required to attend the office physically until an adjustment is necessary. For the busy patient and family this can make treatment less taxing on their time and for the orthodontic office it can free up significant chair time commonly used for progress checks. The technology can be paired very well with 3D setups and thus allow patients to be alerted to attend the office one the wire has become passive.

In terms of clear aligner treatment the technology can alert the patient and the orthodontists should there be a slight misfit on the aligner or should a tooth or group of teeth not be tracking according to the desired plan. The application has gone further as to offer live information for the patient on whether they are ready to progress to the next aligner.

Fixed retainers in their own right can distort and move teeth. However through remote monitoring it is possible to detect subtle changes early and alert both patient and orthodontists that a check of the retainers is in order.

Digital technology is not without its dangers and negatives. The increased availability of 3D printers and digital tools has also allowed the emergence of the do it yourself DIY orthodontic market. There have been several new reports of patients attempting their own orthodontic treatment with homemade appliances. Additionally companies are now providing direct delivery aligners without the patient needing to be properly assessed and diagnosed by orthodontists with the obvious risks involved.

It is also likely that with the rapid increase in simplicity and availability of rapid prototyping and 3D printing that orthodontic manufacturing as we know it will change dramatically. It will be possible to make most appliances in office with in-house printers with little need to pre-manufactures components. This will have a significantly negative impact on the orthodontic manufacturing industry and it also may become a problem for regulators in monitoring the quality of these appliances.

It is likely that in the future orthodontic offices will have desktop printers and most appliances will be manufactured locally and custom made per patient. Robotic wire bending will be common place with wire bending robots becoming available in-office. It is likely that aligner treatment will become more efficient and effective with the creation of direct printed shape memory plastics and will potentially replace braces.

Smartphones are going to be able to perform accurate intraoral scans and it is likely that patients will be able to obtain scan of the mouth using their own hand help devices. It may be possible to have retainers replaced remotely.

In the very near future it can be expected that simpler cases will be mostly treated by either DIY orthodontic providers or automated services with mail order appliances. Orthodontic specialists will still be required especially in the management of more complicated malocclusions. However more work will be done in front of computers, tablets and mobile phones than in the clinic.

Orthodontic education and scientific societies

More and more orthodontists and specialists are turning to social media for information and discussion forums with instant replies and instant access to knowledge and information becoming an expectation. Online forums are rapidly replacing scientific societies and the conventional model of peer reviewed journals and scientific meeting will have to rapidly adapt and innovate in order not to be left behind. Video lectures and live communications via the internet are rapidly becoming the mainstay of education.

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