Abstract
The Dental Implant industry has seen significant advances in the past three decades, however there are still millions of people across the globe with missing teeth that have not enjoyed the benefits of replacing their teeth with dental implants. There are many reasons that prevent patients from choosing implants such as fear, cost, and lack of knowledge. However, even in developed countries there are still many dentists and patients because of the perceived complexity and associated costs.

New digital technologies are beginning to streamline the dental implant workflow simplifying the delivery for the dental implant team. Through advanced digital engineering, dentists are now able to offer precise guided planning, digital impressions, CAD/CAM models, and restorations. These techniques are providing the revolutionary opportunity for the dental team to collaborate and plan dental implant cases virtually with more predictable cost and more predictable outcomes.

Learning Objectives:
1. Develop an understanding of digital impression scanners
2. Learn the procedures involved with taking a digital implant impression
3. Develop an understanding of dental implant treatment planning
4. Develop an understanding of how CAD/CAM is utilized in implant dentistry

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Dr. Bolding enjoys spending time with his family, flying, traveling, boating and golfing.

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Introduction
The art and science of dentistry has provided significant advancements in our abilities to treat patients with both simple and complex dental problems. Over the past twenty-five years we have biologically improved and developed techniques to prevent and treat caries and periodontal disease, replace missing teeth, reposition teeth, and change overall facial structures. Additionally, we have developed wear-resistant esthetic materials that have allowed us to replace the missing teeth with very natural, biologically friendly, beautiful replacements. The past twenty-five to fifty years have allowed dentistry to advance significantly from a professional standpoint, offering patients predictable clinical results.

While the biological sciences and material sciences have allowed for these advancements, we are now seeing evidence of a new wave of digital solutions that are offering even more predictable treatment outcomes. Over the past five years we have seen the introduction of digital radiology solutions, three-dimensional cone beam tomography, digital impressions, digital models, and CAD/CAM (computer-aided design and computer-aided manufacturing) restorations that are now making their way into the mainstream dental practice. These advancements are providing advanced engineering technology to the practice of dentistry that will add to the art and science of dentistry and make it even more predictable and more precise. I call this the Digital Age of Dentistry.

History of digital implant dentistry
Dental Implants are one of the most significant advancements in dentistry in the past two decades. Today, the dental implant is becoming the standard of care to replace missing teeth. The advancements in the science and engineering of dental implants adds a whole new dimension to the replacement of the missing tooth. Not only can dental implants replace a missing tooth, they can absorb load and have the biological capabilities to integrate into the patient’s bone, providing in many cases a lifetime restoration. Dental implant systems have improved their interface attachments at the mucosal surface level of the implant which reduces abutment loosening and enhances overall esthetics. However, while dental implant technology has significantly advanced in the past twenty-five years from both a surgical and restorative standpoint, there have been some limitations. These limitations in many ways have limited the number of dentists that offer dental implants to their patients.

While dental implants have seen significant advancements, these precision designed and engineered fixtures have relied on traditional non-precision manual surgical placement, traditional restorative methods, and traditional laboratory techniques for the delivery and replacement of the missing tooth. This lack of engineering in the delivery of the dental implant has paved the way for the new frontier for dental implants. Dental implant companies are now taking advantage of the new digital solutions in dentistry to improve dental implant ease of use, and provide more precision and cost effective delivery. Precision surgical guided placement using restorative driven three-dimensional imaging and planning allows for more predictable surgical placement. High surface digital impression scanning and CAD/CAM milling allows for precision design and modeling for improved fit and accuracy of both the abutment and restorations. Combining these digital technologies allows the dentist to plan and treat the patient in a more efficient manner with more predictable results. The digital implant dentistry workflow is now redefining and paving a new standard of delivery for the replacement of missing teeth, giving the dental team more confidence when treating their patients.

Intraoral scanning and CAD/CAM in dentistry
One of the critical components of the digital implant dentistry workflow involves the digital capture of the patient’s dentition for planning, placement, and restoration. Intraoral scanning in its simplest form is a way for the dental team to take an impression without traditional impression material and create an accurate virtual model of the patient’s dentition. (Fig 1 and 2) Once the virtual model has been created...
through various CAD/CAM technologies, then an accurate physical model can be created of the patient’s dentition. The first digital intraoral scanner for restorative dentistry was introduced in the early 1980’s by Dr. Werner Mörmann, a Swiss dentist, and Marco Brandestinian, an Italian electrical engineer.

The intraoral scanning devices utilize a sophisticated optical surface scanning technology that works similarly to a camera, but instead of simply capturing lights and colors, the sensors measure light reflection times from various surfaces through processes to capture the object three-dimensionally. This information is then captured by the three-dimensional software that utilizes specific alignment algorithms to allow for registration of the object. In dentistry today there are several commercially available approaches to scanning and capturing detailed intraoral surfaces. Three of the common scanning principles used today by intraoral dental scanners on the market in the United States are triangulation, active wave-front sampling, and parallel confocal laser scanning. Each of these techniques utilize a combination of these various imaging capturing methodologies to collect the surface data of the teeth and mucosa so that the information can be registered and “stitched” together through an alignment process in order to create the virtual three-dimensional model.

The triangulation technique (Figure 4) utilizes a timed laser light that is directed at the tooth structure that is then reflected back to the camera and the data is captured to register the image. The triangulation format allows one angled cone of light to capture a single image at 15,000 microns. These dental scanning systems require that a reflective powder be applied to the teeth prior to scanning to assure accurate capturing of the image. The triangulation scanning technique was first introduced into dentistry in 1987 through CEREC® by Sirona Dental Systems LLC. Additionally, the active wave-front sampling technique (Figure 5) also requires a powder, but instead of using the laser light to capture the tooth data, these scanning systems use a lens with a rotating aperture that allows the capturing of three-dimensional data in a video sequence and models the data in real time (approximately 20 3-D datasets per second). The Lava C.O.S. intraoral scanner by 3M ESPE utilizes this technology.

The confocal laser scanning methodology (Figure 6) projects a laser beam onto the surface of the tooth without a powder and then the immediate reflection along the same ray-path are put through a conoscopic crystal and projected...
onto the camera. The result is a diffraction pattern, that can be frequency analyzed to determine the distance to the measured surface. The confocal approach allows for the scanner to captures 100,000 points of laser light in perfect focus at 300 focal depths of the tooth structure. These focal depth images are spaced approximately 50 microns apart allowing for very detailed capturing of the surface data both inside and outside the tooth, thus allowing for collecting extremely accurate representative structured data. One of the commercially available scanners that utilize this methodology is the iTero® Intraoral scanner by Align Technology, Inc.

**Figure 6. Comparison of Confocal Intraoral Scanner (No Powder Scan) F2/F4 vs. Triangulation and Active Wave-Front Sampling Scanners (Powder) F1/F3**

Once the tooth is scanned and the structured data is captured, software is then used to process each data point to create a geometrical virtual three-dimensional model. This virtual model now can be used by the dentist or lab technician in a variety of applications. The viewing software can allow the dental team to virtually share the models digitally for treatment planning and discussion. Additionally, the dental team can utilize the models to process virtual abutments, copings, crowns, removable prosthesis and other orthotic devices without a physical model through computer aided design (CAD) software applications. Once the CAD software applications have created the virtual geometric three-dimensional model, computer aided manufacturing (CAM) techniques use various printing and milling machines to create an exact replica of the virtual model in a physical form. It is through this process that the dental team can utilize the scanning technology to create more accurate models, abutments, and restorations for the dental implant patient.

**Digital dental implant scanning**

Obtaining an accurate impression to isolate the position of the implant in the patient’s mouth is critical to providing the precision needed for the dental restoration. Traditionally, dental implant impression techniques utilize impression copings that are inserted into the implant at the time of impression. Traditional impression materials such as polyvinyl siloxane or polyether are used to capture the representative teeth and mucosa in the impression tray. Once the impression is taken, the implant analogs are attached to the impression copings and a stone model is created with the analogs representing the positioning of the implant in the model. While this technique has been used in implant dentistry for several years, there are several layers of potential inaccuracies associated with the various steps involved. In order to minimize these steps and streamline the workflow of the implant impression, a digital scan body was created. (Figure 7) The scan body replaces the traditional impression coping and allows the implant fixture to be captured with an intraoral digital scanning device. The scan bodies fit precisely into the dental implant fixture in the mouth to allow for accurate capture of the associated teeth and mucosa in reference to the position of the implant fixture, just as a traditional implant impression coping does. However, the scan body has a precise geometrical shape on the surface to allow for optical capture of the fixture. Once the scan body image is captured and registered the CAD software, through alignment algorithms, can accurately position the implant into the virtual model. (Figure 8) This gives the dental team an accurate impression and a virtual three-dimensional model of the implant, the associated teeth, and mucosa.

**Figure 7. Straumann® Scanbody in patient’s mouth and the iTero® Image of Virtual Model**
Digital implant treatment planning

Virtual capture of the dental implant placement has provided needed precision and increased efficiency for the implant team, but proper surgical placement of the dental implant is still paramount for predictable restorations. Traditional surgical placement of dental implants relies on the surgeon’s surgical skill and judgement to place the implant into the alveolus in a proper position for an ideal restoration. Traditional surgical guides were fabricated from stone models based on the prediction of where the implant position should be in relation to the restoration. While these guides provided the restorative dentist and the surgeon the ideal position of the restoration, they did not take into account the availability of bone for the dental implant fixture. This often led to either failing implants due to inadequate bone around the implant, or the surgeon would have to reposition the implant into a less desirable position.

Through the development of Computerized Axial Tomography (CAT Scan) and Cone Beam Computed Tomography (CBCT) a three-dimensional view of the patient’s jaw bone is now available for implant dentistry. Through the utilization of these technologies the dental surgeon and restorative dentist can now accurately guide dental implant placement with more accuracy.

In the digital implant workflow, the dentist will obtain an intraoral digital scan of the patient’s arches to create a virtual dental model. Today the virtual model is milled to create a physical model and the missing teeth are replaced with radiopaque teeth and attached to a radiographic template guide that has radiopaque reference markers that can be captured by the scan. (Figure 11 and 12) The guide is placed into the patient’s mouth and the CAT or CBCT scan captures the underlying bone structures and radiopaque material in the
The image file from the scan is then uploaded into the CAD planning software so that the reference markers can be identified to allow for software alignment and accurate predictable planning. (Figure 13) Through the software, the dental team then can identify underlying bone quality, proper implant size selection, and placement. Once the virtual implant is positioned properly in the bony image, the software then provides detailed alignment values for the laboratory technician to properly place the surgical guide sleeves into the intraoral surgical guide to be used for the patient’s implant surgery. (Figure 14) The surgeon utilizes the guide during the implant surgery to place the dental implants into the pre-planned sites, thus providing more accurate and predictable placement. (Figure 15)

Now that more predictable placement is achievable through guided surgical planning, the digital implant workflow is enhanced. Just as the surgeon is capable of predictably placing the dental implant into the patient’s mouth, the laboratory technician can utilize the same surgical guide on the physical implant model and place an implant analog into the model. Once the implant analog is placed in the model, then a customized provisional can be fabricated on a temporary abutment to allow for delivery at the time of surgical implant placement if so desired. This allows for ideal sculpting of associated tissues and leaves the patient with a provisional restoration at the time of surgery. Modelless fabrication of surgical guides and provisionals will be possible in the future as CAD/CAM planning software and milling or printing technologies continue to advance, thus further enhancing the overall digital dental implant workflow.

Figure 13. Straumann® coDiagnostiX software planning Straumann Implant in the Bone and iTero® scan imported into coDiagnostiX
Digital implant dentistry in practice

There are over 100 million teeth replaced annually worldwide today. Unfortunately, only 15% of the patients that receive replacement are benefiting from dental implant technology. However, the latest advancements in digital implant dentistry will continue to streamline the dental implant workflow and should provide the dental team with a more predictable methodology for restoring the missing tooth.

While digital implant dentistry will continue to become more predictable and efficient for the dentist, many dentists and patients will continue to offer dental implants through a referral team approach. The conventional relationship between the dental implant surgeon, restorative dentist and lab will continue to exist. Through the technological advancements in digital implant dentistry the workflow will streamline and enhance the overall collaboration between the dental implant team making the workflow more predictable, cost effective, and convenient.

Conventionally, the implant surgeon and the restorative dentist work separately, with the surgeon rarely involved in the restorative and laboratory process. Many times, this lack of involvement in the restorative process inhibits the surgeon’s understanding of the final restorative plan and can lead to not only unfavorable results, but also an increased cost of supplies and parts for both the restorative dentist and surgeon. Unless the surgeon and restorative dentist have constant communication or meetings which are difficult to do with busy practitioners, it creates a breakdown in collaboration and confidence as a team. This is a primary reason that many practitioners do not offer dental implants to their patients. Through the digital implant process, however, the implant surgeon, the restorative dentist, and the lab technician are connected digitally and can review and plan the case virtually throughout the treatment process. The restorative dentist will have more confidence in recommending dental implant options because the digital workflow will allow the restoration to be more predictable with fewer hassles, lower cost, and more profitable.

The digital dentistry workflow begins with the evaluation. When the patient presents with a missing tooth the implant option should be in most cases today the recommended option. The restorative dentist or surgeon will digitally scan the patient’s arch with an intraoral scanner and create a virtual model for treatment planning. Once the restorative option is selected, a radiographic guide is created for the patient from the digitally processed models. The patient then receives a CBCT or CAT scan with the radiographic guide. The images are then transferred to the implant planning software. The appropriate implant size is chosen and positioned into the underlying bone image. If there is inadequate bone, the restorative plan may need to be altered, or bone grafting may be necessary either at the time of implant placement or before an implant can be placed. After the digital implant planning is complete, the information from the software is transferred to the laboratory technician. The radiographic guide can then be converted into a surgical guide by placing the appropriate surgical guide sleeves to facilitate proper implant placement. The surgeon will then utilize the surgical guide at the time of surgery to place the dental implant in the ideal position. After the implant is placed into the patients arch, a scanbody can be used either at the time of surgery or after integration to allow for an intraoral impression scan to capture the implant placement in the dental arch either by the surgical team or restorative team. Generally the intraoral impression is performed after integration to assure final tissue position and a cleaner field for scanning. The digital impression is then transferred to the laboratory technician with the restorative prescription attached. The laboratory technician confirms the transfer and digitally plans a virtual abutment and restoration. The crown can be created virtually and milled, or the crown can be created conventionally from of the digitally milled physical models and abutment. The restorative prosthesis is returned to the dentist and the abutments are inserted along with the final restoration. Additionally today, removable dentures are beginning to
be processed digitally (AvaDent™ Digital Denture is a Trademark of Global Dental Science. All Rights Reserved. © Global Dental Science LLC 2012) (Figure 16) and will ultimately play a role in the removable and fully fixed dental implant patient in the future.

Figure 16. This screenshot shows a computer designed AvaDent with implant housing pockets.

Conclusion
Digital Implant Dentistry will have an enormous impact on the dental implant market in the near future because of the predictable results, more predictable cost, and improved efficiencies with the workflow. These increased efficiencies through digital implant dentistry workflow will help control cost and save time for both the patient and the dental team. Digital planning and processing will also make the dental implant treatment option much less burdensome and easier to deliver for the dental implant team and patient, thus improving acceptability and utilization globally. It is predictable that dental implants will become the most common replacement option for the missing tooth as we evolve further into the digital dental age.

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1. What is the name of the digital implant impression coping?
   a. Analog
   b. Pick-up Impression Coping
   c. Transfer Impression Coping
   d. Scanbody

2. What is the definition of CAD/CAM?
   a. Computed Aided Development/Computer-Aided Mechanical
   b. Computer Aided Design/Computer Aided-Manufacturing
   c. Comprehensive Aided Design/Comprehensive-Aided Milling
   d. Computer Aided Development/Computer Aided Milling

3. Guided Surgical Implant Placement allows for more predictable placement by utilizing three-dimensional planning software and the associated
   a. Periapical Radiograph
   b. Impression
   c. Stone Model
   d. Computerized Tomography

4. Who created the first intraoral digital scanner?
   a. Dr. Werner Mormann and Marco Brandestinian
   b. Dr. Harvey Smith and Scott Bell
   c. Dr. Michael Carter and Henry Matthews
   d. Albert Hanby and Dwight Duckworth

5. Intraoral Scanner technology works through sophisticated optical surfacing scanning techniques that measure?
   a. Red Lights
   b. Colors
   c. x-ray beams
   d. Light Reflection Times

6. What type of intraoral scanner utilizes a time laser light that is directed at the tooth and requires a powder that is then reflected back to the camera to capture the image?
   a. Confocal Laser
   b. Parallel Laser
   c. Triangulation
   d. Active Wave Front Sampling

7. What type of intraoral scanner reflects a laser beam from the surface of a tooth without a powder and projected through a crystal to capture the image?
   a. Confocal Laser
   b. Parallel Laser
   c. Triangulation
   d. Active Wave Front Sampling

8. What was the first intraoral scanners were introduced commercially in to dentistry?
   a. Impress
   b. CERAC
   c. Itero
   d. LAVA C.O.S.

9. Confocal Laser scanning allows the scanner to capture how many points of laser light in perfect focus?
   a. 50,000
   b. 1,000,000
   c. 250,000
   d. 100,000

10. Which Scanner utilizes the Parallel Confocal Scanning Technique?
    a. Itero
    b. CERAC
    c. LAVA C.O.S.
    d. Impress

11. Once a Scanner captures a tooth image three-dimensionally, then the image can be transferred to a physical model through the following process.
    a. Precise Milling
    b. Stone Modeling
    c. Virtual Modeling
    d. Wax-Up

12. How is the digital surgical guide referenced to the three-dimensional software for planning?
    a. The dentist must align the teeth edges from the radiograph
    b. There are Radiographic markers mounted to the guide
    c. The software automatically can determine tooth position
    d. The digital surgical guide does not require radiograph

13. The digital surgical guide allows the surgeon to place an implant more precisely and more predictably the following:
    a. Place Custom screw retained provisional
    b. Place more implants at the time of surgery
    c. There are no advantages
    d. Place a Healing Abutment

14. Globally in 2011 what are the percentage of implants utilized to replace missing teeth?
    a. 70%
    b. 38%
    c. 4%
    d. 15%

15. The Active Wave Front Scanning technique utilizes a rotating lens and captures the three-dimensional data through the following.
    a. Triangulation
    b. Video Sequencing
    c. Parallel Imaging
    d. Reflective Lighting

16. An example of an Active Wave Front Scanner on the Market today is the following.
    a. CERAC
    b. Itero
    c. Lava C.O.S.
    d. Glidewell

17. Once the data points are captured from an intraoral scanner the image points are manipulated together through the following process to visualize the final image.
    a. Stiched
    b. Blended
    c. Morphed
    d. Carried

18. The parallel confocal scanner captures laser light points at 300 focal depths of the tooth structure and spaces them how far apart to insure extreme accuracy?
    a. 100 microns
    b. 50 microns
    c. 2 mm
    d. 500 microns

19. How does the scanner capture the scanbody information from the digital impression?
    a. Through Reference Pins
    b. It cannot capture the scanbody
    c. Reference Geometrical Shape
    d. Dow Pins

20. The scanbody best allows for digital capture of the following.
    a. Dental Implant Position
    b. Tooth Position
    c. Occlusion
    d. Inter-arch distance

21. Digital Scanning of dental implants allows for the dentist to best do the following.
    a. Models
    b. Crowns
    c. Abutments
    d. Screws

22. Digital Scanning of dental implants can provide for virtual development of all of the following except?
    a. Models
    b. Crowns
    c. Abutments
    d. Screws

23. Digital Scanning of dental implants compared to conventional impressions is the following.
    a. Equal to or More Accurate
    b. Less Accurate
    c. Equal to or Less Accurate
    d. Digital Scanning is not possible of dental implants

24. Digital Scanning of dental implants a. Decreases workflow time for the dental team
   b. Increases workflow time for the dental team
   c. Eliminates the need for laboratory technician
   d. Increases cost for the patient

25. Digital Implant Treatment Planning
    a. Eliminates the need for surgery
    b. Allows for easier workflow and virtual communication
    c. Increases time required by the patient
    d. Eliminates abutment requirements
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