Chapter 13
Digital Occlusion in the Workflow of Implant Rehabilitations

Henriette Lerner, DMD
Goethe University Frankfurt, Germany

ABSTRACT

Contemporary implant rehabilitations are esthetically driven. Consequently, digital planning and guided surgery deliver higher esthetic predictability and precision than do analog procedures. The aim of this chapter is to show the integration of digital occlusion in the different phases of full arch implant rehabilitation with immediate implant placement and immediate loading procedures. Digital occlusal analysis raises the precision of functional occlusal adjustments, while improving the long-term predictability and stability of both case function and esthetics. This chapter will present a systematic digital workflow detailing every stage of full arch rehabilitation treatment, while showcasing digital occlusal diagnosis with the T-Scan 9 system, to install a precise implant prosthesis occlusal scheme. A full arch rehabilitation case involving immediate implant placement and immediate implant loading will be presented, with it occlusally finished with the T-Scan.

INTRODUCTION

The digital era has created a new dental discipline. Implant rehabilitations that follow a path of immediate placement and loading, which is today a predictable procedure with high success rates (Misch, et al., 2004; Schwarz & Arad, 2012) documented to be 98% success in the mandible, and 97% in the maxilla (Tarnow, et al., 2010).

Lately, the esthetic and functional criteria that are being considered parameters of success in multiple implant rehabilitations, are also being researched. (Kinsel & Lamb, 2000; Buser & Belser, 2004; Spiekermann, et al., 2009). Experience shows that in implant rehabilitations, a perfectly adapted occlusion is more important than in the natural dentition, or in dental supported prosthetic constructions. Therefore, an initial, precise diagnosis of the masticatory system components is necessary, as an implant

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rehabilitation in a compromised functional environment that can lead to an irreversible aggravation of the initial dysfunction.

This is based on the fact that an implant supported dentition has structures which lack the physical proprieties of resiliency, elasticity, and forgiveness. There is no periodontal space around implants, where implant mobility is 4 microns, which is far less than natural teeth loading motilities of 25 - 200 microns. Additionally, E max abutments, and E max (IPS E Max, Ivoclar Vivadent AG, Schaan, Liechtenstein), or Zirconia prosthetic parts, have different moduli of elasticity and resilience compared to natural teeth, such that without resilience, occlusal wear does not exist or adapt.

It has been proven that due to implant overload or incorrect loading, bone loss around implants can compromise the implant reconstruction and lead to peri-implantitis and bone loss (Naert et al., 2012). Often, poor patient occlusal adaptation results from the lack of resilience, which can be followed by the development of muscular disorders and prosthesis structural damage. For sound muscular function and long-tern maintenance, a very precise occlusal force profile is necessary.

This chapter will present a systematic Digital Workflow that utilizes occlusally-focused steps to assure a physiologic reproduction of the initial masticatory and muscular system was transferred onto implant rehabilitated tissues, despite changes in the vertical dimension. These steps are:

- Occlusal and functional diagnosis and registration at the first appointment
- Occlusal adjustment of the provisional, immediate restoration
- Reproduction of the digital contacts in the digital planning procedures of the future reconstruction
- Occlusal control of the final restoration at delivery
- Yearly occlusal and functional maintenance of the implant supported reconstruction over the long-term.

A complete full arch rehabilitation involving immediate implant placement and immediate implant loading, that was occlusally finished with the T-Scan 9 (Tekscan Inc., S. Boston, MA, USA), will illustrate each of these steps in great detail.

BACKGROUND

Occlusion is the relationship of all the components of the masticatory system in normal function. There is a special reference to the position and contact of the maxillary and mandibular teeth for the highest efficiency during mandibular excursive movements that are essential for mastication (Jablonski, 1992). Occlusion can be dynamic or passive, whether it is registered in Centric Relation (CR) or Maximum Intercuspation (MIP).

Centric Relation is the position of the mandible in relation with the maxilla, where the mandible is aligned such that the mandibular condyles are seated posterior and superior within the glenoid fossa (Dawson, 1995)

Stomatognathic function includes, mastication, deglutition, speech and respiration.

- Mastication is a physiologic action during which the mandible moves cyclically when tooth contacts can glide across each other or occur statically in complete intercuspation. The average time duration of tooth contacts during mastication is 194 milliseconds.

The forces of mastication differ from individual to individual, but an average female can generate 79-99lb (35.8-44.9 kg) of occlusal force, while the average male can produce 118-142 lb. (53.6-64.4 kg) of occlusal force. Furthermore, the maximum amount of force applied to a molar exceeds that of the incisor by several times. A central incisor receives 29-51 lb. of occlusal force, whereas a first molar can receive 91-198 lb. of occlusal force (Nishimori, et.al.,2016)

In comparison with a natural tooth, the direct bone interface of an implant is not resilient, due to the absence of the periodontal space and ligament. Therefore, the energy imparted from occlusal forces is not partially dissipated on an implant, but instead transmits a higher intensity force to the contiguous bone. This occurs more often with the contemporary implant prosthetic materials (IPS E max. press ceramics, ZrO_2 stabilized with Y_2O_3), which have higher fracture and flexural strength (400 MPa), but far less elasticity (90 GPa) or wear-ability than do natural teeth.

An implant supported prosthesis needs special attention and precision to protect the bone and tissue infrastructure, while also preserving the prostheses' stability and its' esthetics, over time.

Therefore, a special, precise and regular control and adjustment of the implant supported dentition is necessary.

Initial Clinical and Functional Diagnosis

The presented patient is a 35-year-old female who has severe, chronic periodontal disease, with mobility grade 2 - 3 of her maxillary teeth (Figures 1 - 4).

Figure 1a. The initial presentation of the patient from the side, with unsatisfactory esthetics. The extreme elongation and flaring of many mobile maxillary teeth is apparent

Figure 1b. The initial presentation of the patient from the front. There are many elongated, flared, and loosened maxillary teeth

Figure 2. Panoramic radiograph shows multiple teeth with periodontal bone loss, in excess of half the tooth's length

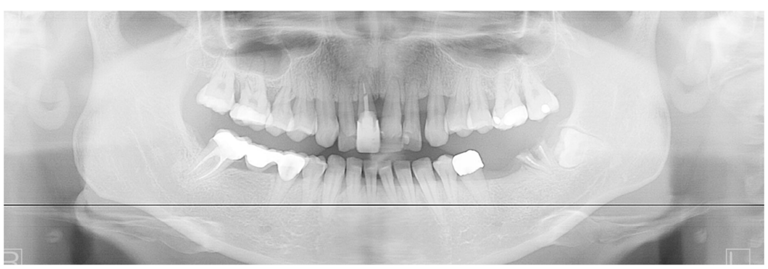


Figure 3. Soft tissue recession with teeth elongated and multiple insufficient composite fillings

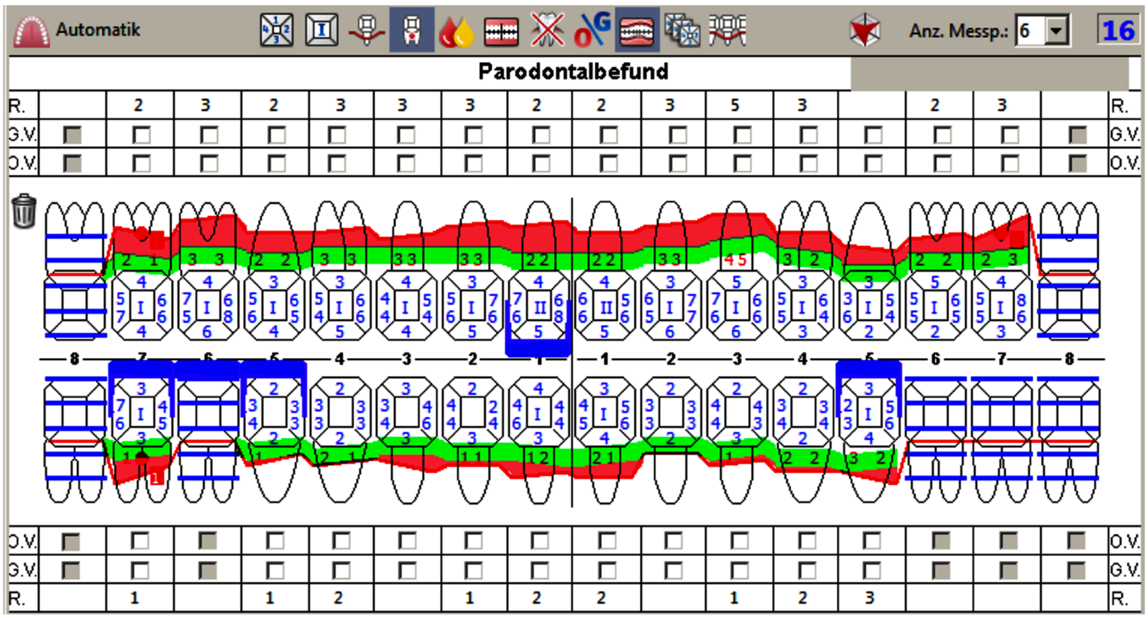
Figures 4a. Right side with extreme overjet visible, due to the elongated and flared teeth resultant from periodontal bone loss

Figures 4b. Left side of the arch with a missing lower molar, and exposed roots from visible periodontal recession

Figure 5 is the Periodontal Chart after 1 year of conservative periodontal therapy that included scaling and root planing.

Many patients whom need their teeth replaced with implants are partially or fully edentulous, or have periodontal disease associated with significant tooth mobility and elongation. Some also present with occlusal disharmonies and muscular discoordination, despite not experiencing pain or other chronic symptoms. This discoordination occurs slowly over time, leading to a certain adaptive behaviour and lack of symptoms. It is essential that a functional and occlusal diagnosis be completed before rehabilita-

Figure 5. Periodontal charting after 1 year of conservative periodontal treatment was performed. After 1 year of treatment, we managed the stabilization of the teeth 42, 43, 44, 45 and 32, 33, 34. The chronical infection and mobility of the rest of the teeth was still present, and a residual bone height of 7 mm in the maxillary molar aria is to be observed.



tion, so that any dysfunction can be corrected prior to performing all the procedures required for a new implant supported reconstruction.

The presented patient is complaint free, where the functional analysis is unspectacular. The occlusal analysis approach used when planning an implant prosthetic treatment involves:

1. Examining the patient's edentulous anatomy and tooth structure intraorally
2. Photographing existing clinical conditions (Figures 3, 4)
3. Imaging the available bone and teeth
4. A digital method of occlusal analysis

The digital occlusal analysis is a dynamic registration. Through examination of the resultant diagnostic movies, premature contacts and zones of excessive occlusal force can be identified, as these are critical in the etiology and control of the tooth mobility in periodontal patients (Kerstein, 2015). Multiple different studies by Carey, Qadeer, Kerstein, Radke, and Sutter, (Carey, et al., 2007; Qadeer, et al., Kerstein & Radke, 2013; Sutter, 2017) all show that articulating paper markings have less than 20% correlation to the actual forces (Figure 6).

5. Making impressions and mounting articulated study casts of the esthetic wax up on a fully or semi adjustable articulator (Figures 7-11).

Figure 6. Digital occlusal registration with the T-Scan 10 system. Premature contacts due to unequal elongation of teeth leads to additional tooth mobility and bone loss.

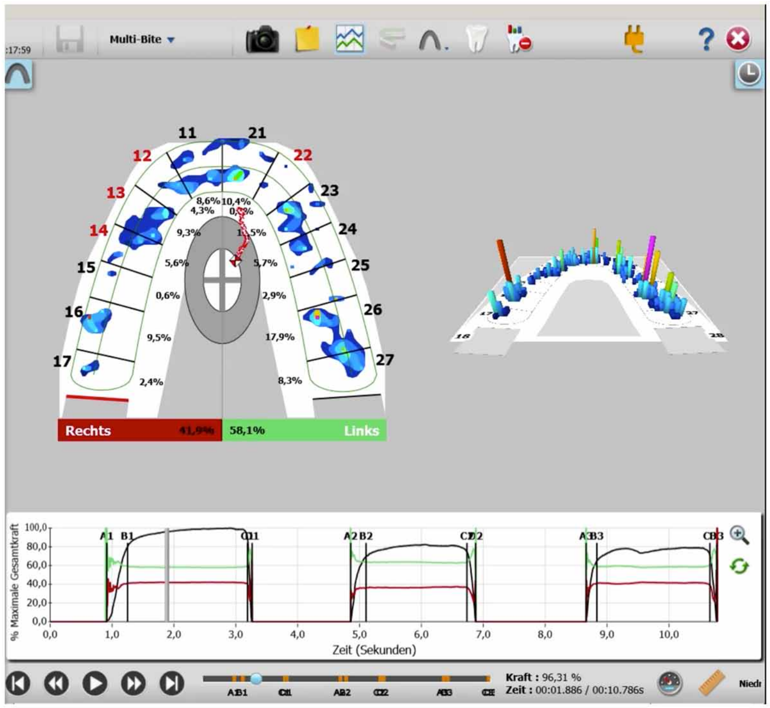


Figure 7a. An esthetic correction to correct the teeth proportions will begin with an analog wax up

Figure 7b. The analog wax up correcting the many esthetic flaws the patient presents with, while also designing in the occlusal design of the provisional restoration

Figure 7c. The final esthetic design of the analog wax up scanned in, for use when creating the esthetic tooth shapes of the provisional restoration

Figure 8a. Occlusal view of the maxillary analog wax up. Stone casts of both the mandibular and the maxillary wax ups will be produced for laboratory scanning

Figure 8b. The maxillary stone cast made from the analog wax up

Figure 9. Analog casts of the wax up articulated into MIP occlusion; frontal view

Figure 10. Analog casts of wax up in MIP occlusion; left side view

Figure 11. Analog casts of wax up in occlusion; right side view

Planning Considerations and the Treatment Plan

There is always a decision tree or a consensus, as to how long and under what conditions a tooth with periodontal disease should be treated or extracted. This consensus is best determined by analyzing the stability of the residual bone, and not necessarily the status of the tooth. The most recent literature suggests that if 1-year of periodontal treatment has not been successful in saving a tooth, and the remaining vertical bone height < 10 mm, the tooth should be extracted in favor of initiating implant treatment (Lorenz, et al., 2017).

After 1 year of several conservative periodontal treatments, (scaling, motivation, re-motivation and decontamination with photodynamic therapy), the presented patient maintained mobile teeth in the maxilla, with inflammatory liquid indicative of chronic inflammation still present in all maxillary sulci. Alternatively, the mobilities of the mandibular teeth #s 32, 33, 34 and 42, 43, 44, and 45 were acceptable, with no pus within the sulcus, and pocket depths reduced to 3-4 mm.

The treatment plan should consider the age of the patient, and the long-term stability of both the esthetics and the function. In selecting which natural teeth are to be included in a new reconstruction, restorations are planned to function for 15-20 years. Therefore, a protocol of tooth selection for 5 -10 - 20 years of maintenance, is routinely followed.

Teeth which have a prognosis of < 5 years according to the literature, are excluded from a proposed construction Teeth that have prognosis approximating 10 years are included in the treatment plan to be easily be replaced or corrected, should they fail before 10 years without compromising the entire reconstruction.

Next, the analog wax up is optically scanned to transform the wax ups into .stl files to generate the virtual planning casts (Figures 12a and b).

As the wax up is the designed future provisional restoration, all occlusal, functional, and anatomical issues need to be corrected within its' form, to ensure the patient exhibits future, harmonious function.

In the presented patient's case, there is no need to change the occlusal vertical dimension, although the occlusal plane, the cuspal inclinations, and functional alignments need optimization. Further, a full mouth restoration on implants doesn't have any "resilience", so all the contacts need to be very well adjusted.

A treatment plan on fixed teeth was then initiated, incorporating an immediate implant placement and immediate loading procedure (Figure 13).

Figure 12a. The facial view of the virtual maxillary cast used in the digital planning

Figure 12b. The occlusal view of the scanned waxed up contours on the virtual maxillary cast that is used in the digital planning

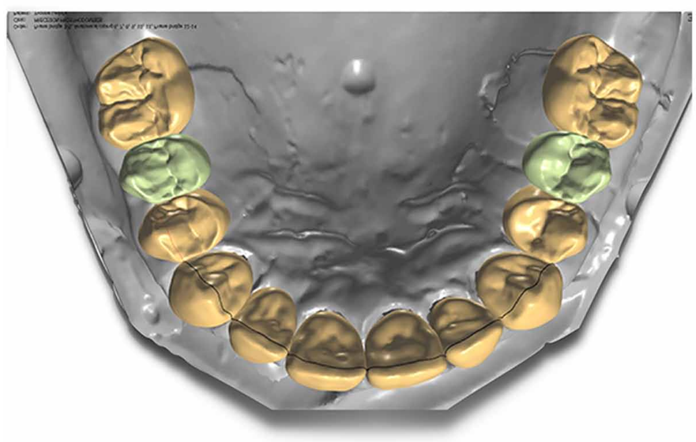


Figure 13. Patient information and visualization of the future reconstruction, rendered in 2 and 3 Dimensions (Dental Master, Personal Assistant, Tel Aviv, Israel)

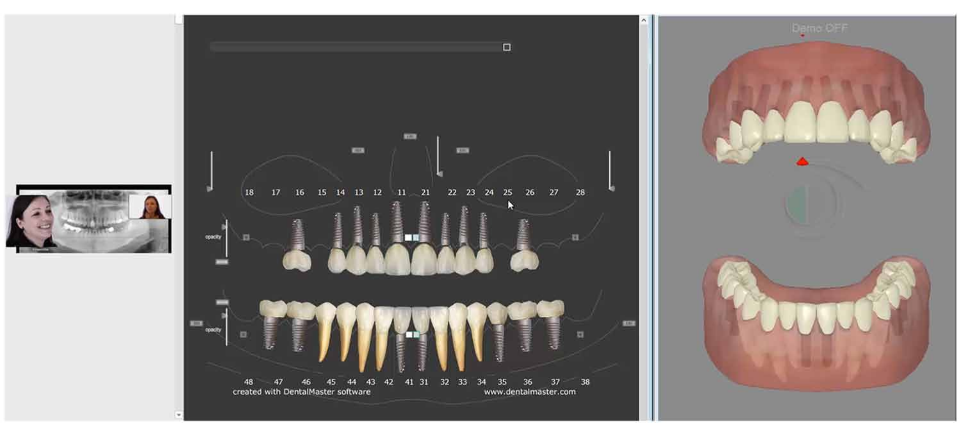


Figure 14. The Digital Workflow for immediate placement and restoration in full arch reconstructions on teeth and implants

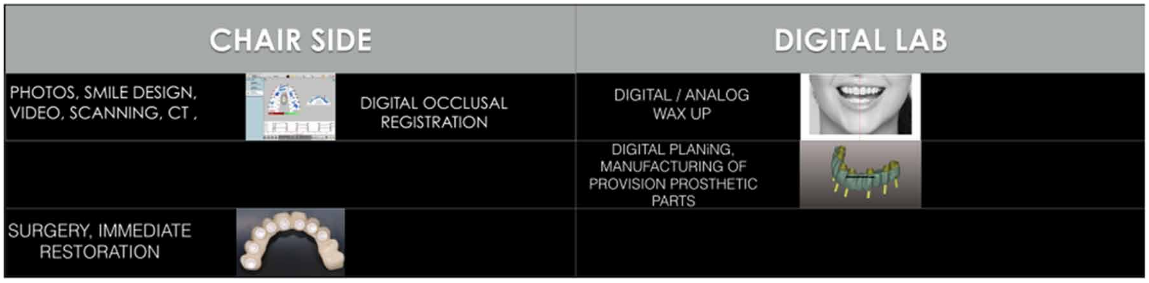
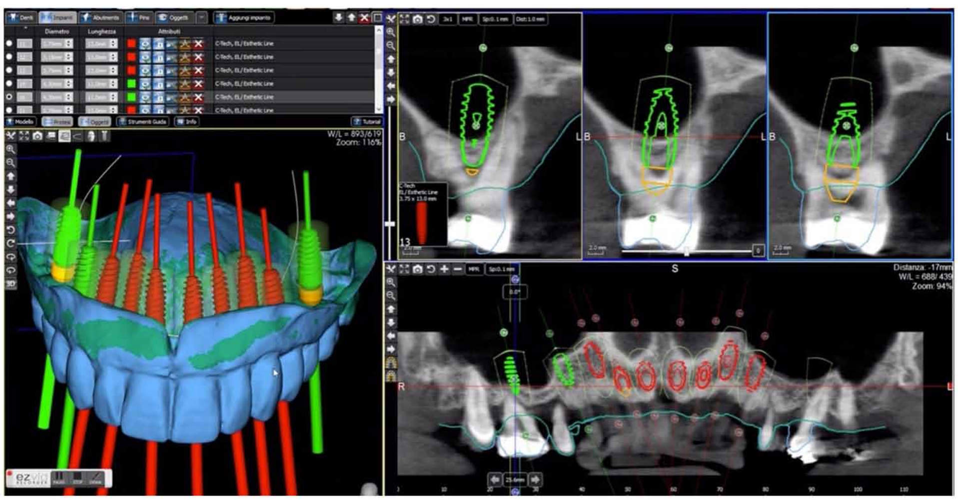


Figure 15. Planning the implant placements in the ideal esthetic and bony positions



The digital workflow has initial chairside procedures that are followed by planning stages and laboratory manufacturing steps, which all precede the last chairside procedures (Figure 14).

To perfectly position the implants, superimposing the .stl files onto the cone beam CT Dicom data is accomplished, to plan the provisional reconstruction and to create a surgical guide (Figures 15 - 18). In the presented case, immediate single implant placements were planned for the #s 14 - 24 extraction sites. Alternatively, teeth #s 15 and 25 were maintained to support the surgical guide before finally being extracted (Figures 18a, b and c).

The digital planning of implant placement has enormous advantages in both the case esthetics, and in the biomechanical outcome of the combined implant/tooth reconstruction. The implant can be placed with high precision, within the axis of the tooth root. The bone thickness around implants (2 mm) and the tissue thickness are both under control, but can be augmented by grafting, if necessary. This ensures a protective and harmonious peri-implant repartition of the forces, assuring long-term stability of the structures despite higher stress forces (Misch, 2000). It is well known that non-axial loading of the implant will lead to bone loss, and in a thin tissue biotype, to recession, which will influence the esthetic outcome of the reconstruction and the stability of the esthetic outcome for many years

Figure 16a. Implants are planned to be placed in biomechanically and esthetically precise positions

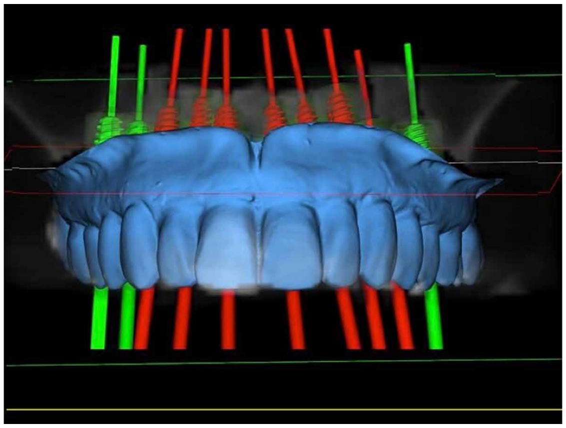


Figure 16b. Occlusal view of planned implant placements that biomechanically attempt to avoid non-axial forces and peri-implant bone loss

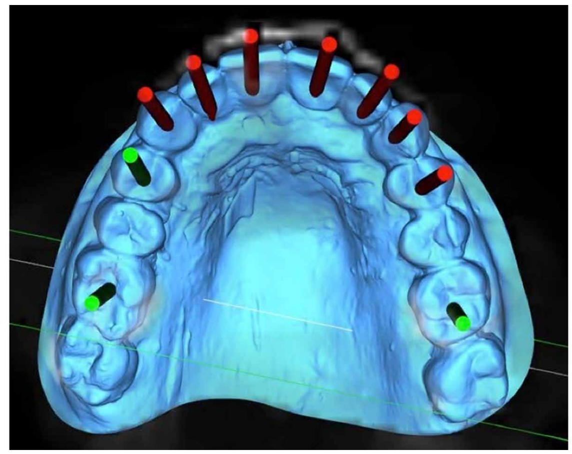
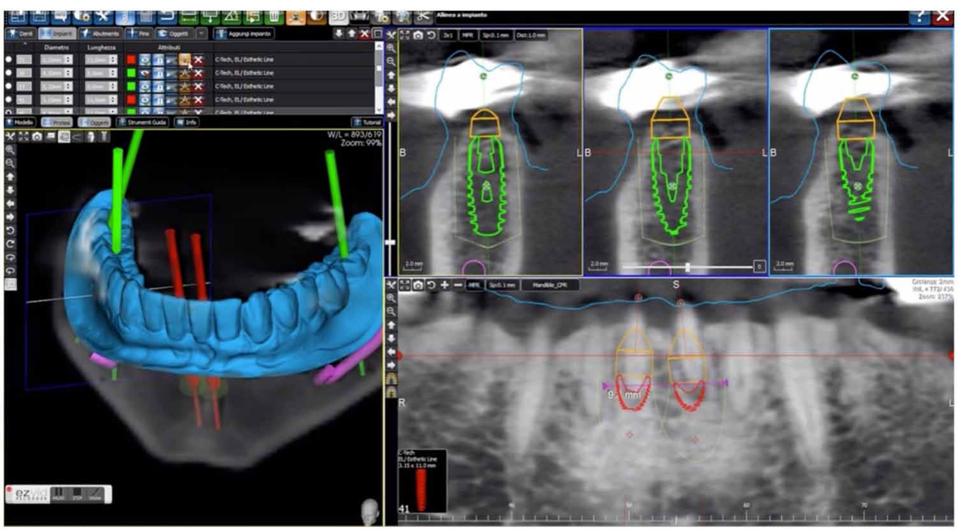


Figure 17. An equal amount of bone will be planned around the future implants



Surgical Procedures

The immediate placement of implants requires good initial stability, such that the maximum movement permitted to ensure implant integration is 150 microns (Misch et al., 2000). The protocol for immediate loading of implants placed into extraction sockets was formulated in 2004 (Tarnow, et al., 2004), whereby all implants should be rigidly splinted with a metal frame (Figures 19 - 21), and the patient is allowed to chew only soft foods during the period of osseointegration.

In the presented case, the mandibular implants were inserted in the precise position determined digitally, but without immediate loading. This reduced the patient's mandibular arch length.

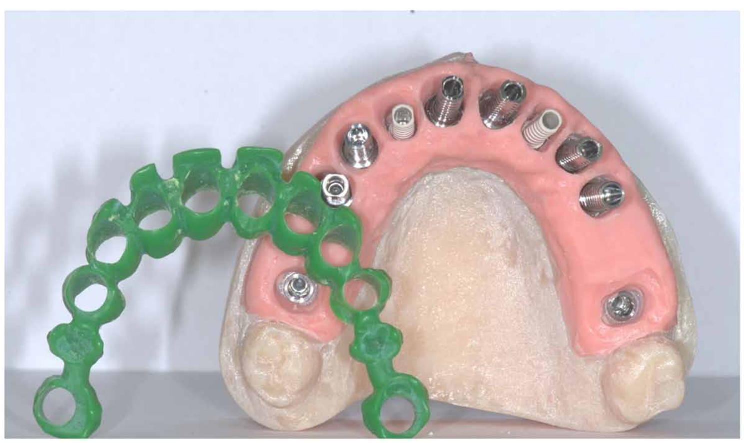
Figure 18a. Mandibular surgical guide with underlying tooth support helps properly orient the guide drill, intraorally. Here, a single metal drill orienting sleeve is in place

Figure 18b. A 2nd mandibular surgical guide with 5 metal drill orienting sleeves in place

Figure 18c. The maxillary surgical guide with 10 metal drill orienting sleeves in place

Figure 19a. The printed maxillary cast with the provisional screw-retained abutments, and the provisional bridge frame in wax, seated on the abutments

Figure 19b. The printed maxillary cast with the provisional screw-retained abutments and the waxed provisional bridge frame



Following atraumatic extraction, a flapless surgical procedure was performed, with the exception of the region of #s16 and 26, which required implant placement and a simultaneous sinus elevation procedure (Figures 22 - 24). In a recent systematic review of the accuracy needed to succeed with digital planning of the implant placement and the provisional fabrication, the overall mean error should be no more than 0.74 mm - 1 mm from the planned surgical entry point, and within 0.85 mm at the apex (Jung & Wismeijer, 2019). When performing immediate placement surgery, it is important to consider these values, so as to stay within the digitally planned surgery's secure zone.

Figure 20. Provisional splinted crowns made out of PMMA with an embedded metal frame

Figure 21. Mandibular milled PMMA provisional to use with the "egg shell" technique

Figure 22. Maxillary atraumatic extractions, except for teeth #s 15 and 25

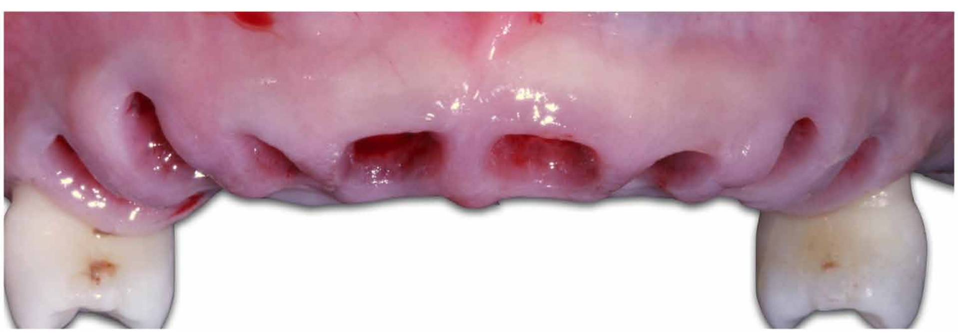


Figure 23. Precise positioning and flapless placement of the implants within extraction sockets

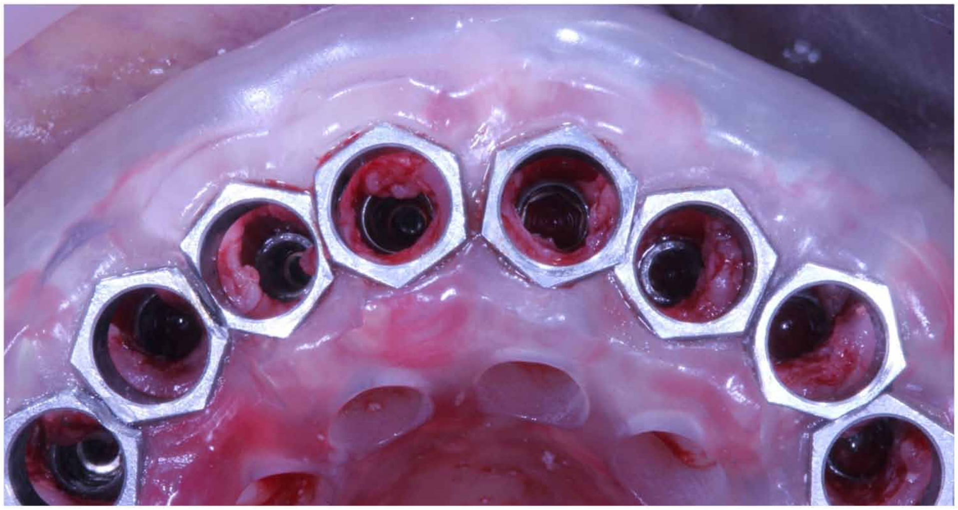


Figure 24. The implants are positioned well within the extraction sites. The thick tissue biotype is favorable for an esthetic outcome, without needing buccal soft tissue grafting

The maxillary provisional restoration is prepared for insertion by opaquing out the metallic color of the provisional screw-retained abutments (Figures 25a and b).

At the completion of the immediate placement and immediate loading surgery, the patient was restored with a stable occlusion on the two provisional restorations. After a few days of healing, she had a very positive response (Figures 26 - 28).

The Immediate Restoration Is Utilized for 4 - 6 Months

Although the occlusion will be protected somewhat by the patient's soft food diet, a balanced distribution of forces should be achieved through adjustment during the provisional phase. After a few days, the occlusion on the provisionals was adjusted digitally with the T-Scan 9 system. The occlusal forces were too high on the provisional, necessitating force reduction to establish a functional, balanced baseline.

Figure 25a. The maxillary provisional screw-retained abutments with opaquer applied, to block out their metallic color from showing through the installed maxillary provisional

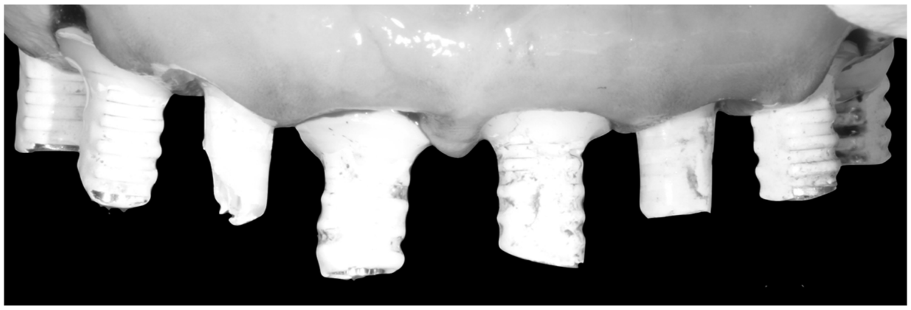


Figure 25b. The maxillary provisional ready for insertion onto the screw-retained abutments

Figure 26. Close- up of the patient 2 days' post-immediate implant placement, with both provisionals in place

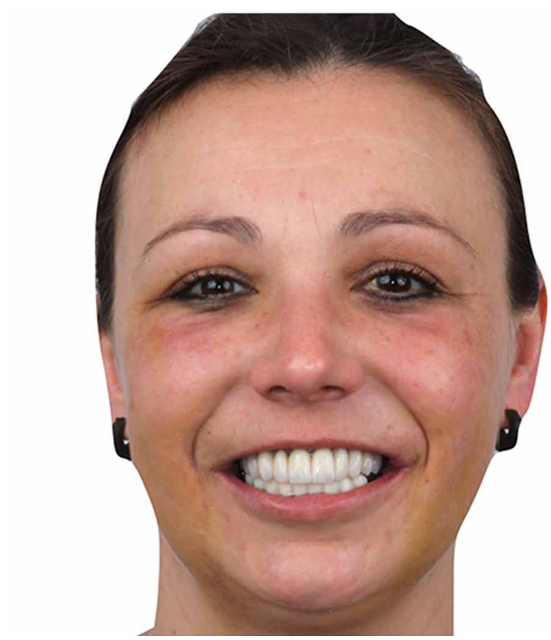
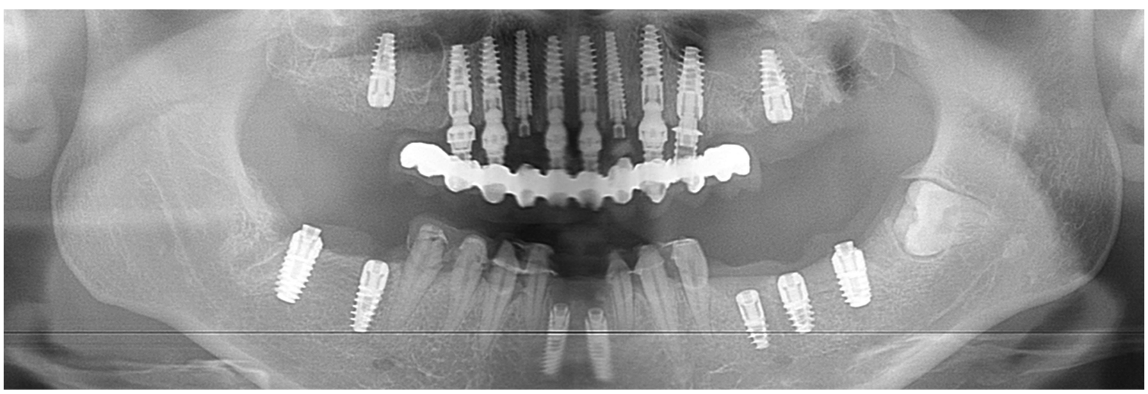


Figure 27. The patient's clinical condition 5 days after surgery. Note there is very little visible tissue inflammation

Figure 28. The post-surgical panoramic radiograph with the implants supporting the metal frame of the maxillary provisional restoration. All implants appear well-embedded, and in close proximity to the surrounding bone



The problem of using solely articulating paper when adjusting the implant occlusion in a mixed dentition, is that the paper mark size and color intensity that results from thickness of the paper, offers the clinician no quantitative data about the sequential order of occlusal contacts, or of the force distribution (Qadeer, et al., 2012; Carey, et al., 2007, Saad, Weiner, & Ehrenberg, 2008; Kerstein & Radke, 2013; Sutter, 2017). Whereas, when using the T-Scan to guide the implant occlusal adjustments, a clinician can see within the Center of Force (COF) trajectory, the quantitative distribution of the forces (Figure 29).

THE FINAL RESTORATION

After 4 - 6 months, a digital or analog impression is made of the implants and the provisional, which is why the provisional anatomic shape and occlusal contours need to be a close as possible to those same aspects of the final restoration. (Figures 30 - 32)

Figure 29a. The ink makings can mislead a clinician to incorrectly assuming high forces exist on the right side only, when selecting areas to adjust

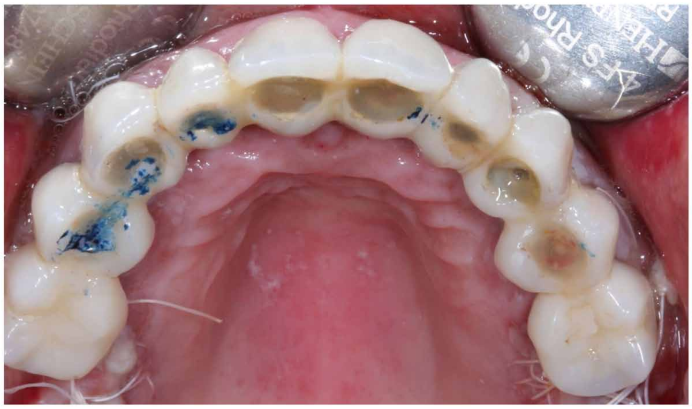


Figure 29b. Digital occlusal adjustment of the provisional restoration. Note in the T-Scan data there are some high forces on the patients left side where there are small ink marks. On the right side, there are dark ink marks also demonstrating high forces. The 7 implant warning signs denote that many implants supporting the provisionals are at risk from occlusal overload

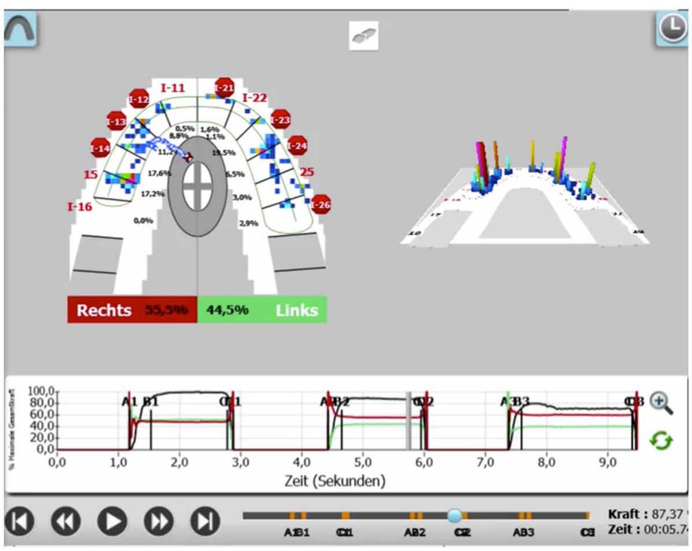


Figure 30. The workflow of the final restoration describing both the chairside and laboratory procedures, commenced 6 months after the implant and provisional installations

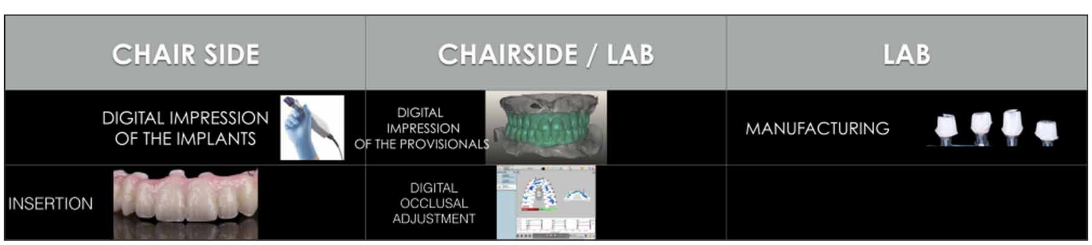


Figure 31. Analog impression to be made over the implants

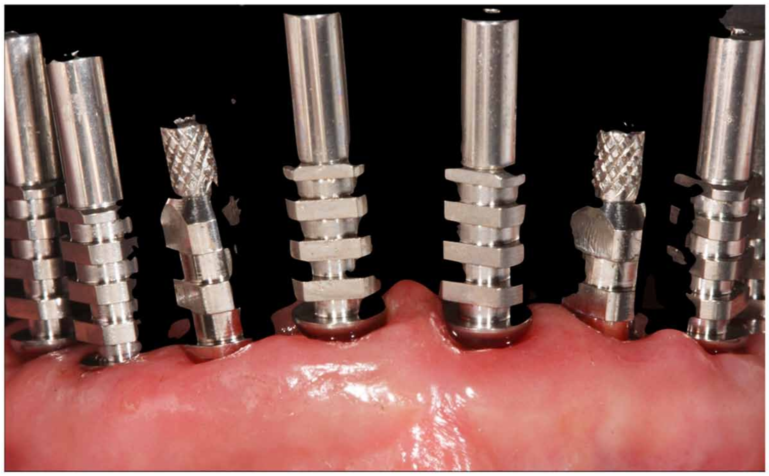


Figure 32. The analog impression is to be made with an open tray

It was observed that the proportions of the peri-implant tissues were properly fulfilled (Figures 33 - 36) by respecting the parameters, distances, and design aspects of the final prosthetic parts. This will lead to a nice and pleasing tissue appearance around the final restoration (see Figures 40 - 43).

Figures 37 - 43 illustrate the digital creation, the milled fabrication, and the intraoral insertion of the Zirconia custom abutments. Their designed emergence profile fits properly within the soft tissue contours established by the provisional restoration.

Digital Occlusal Adjustment of the Final Restoration

Following this pleasing esthetic result, a first digital adjustment is undertaken. In this case, there are more implants than natural teeth, so the time delay principle will not be appropriate (Kerstein, 2002).

Figure 33a. The depth of the tissue height above one implant measured with the periodontal probe. There is very good tissue height coronal to the implant

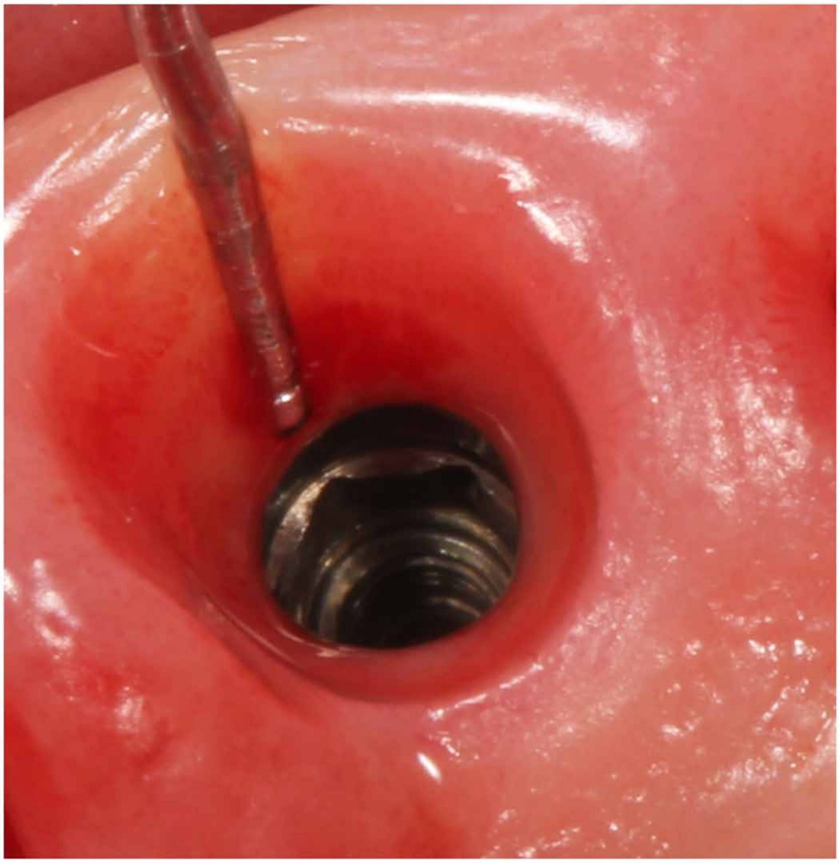


Figure 33b. Tissue view of the abutment connection and screw access

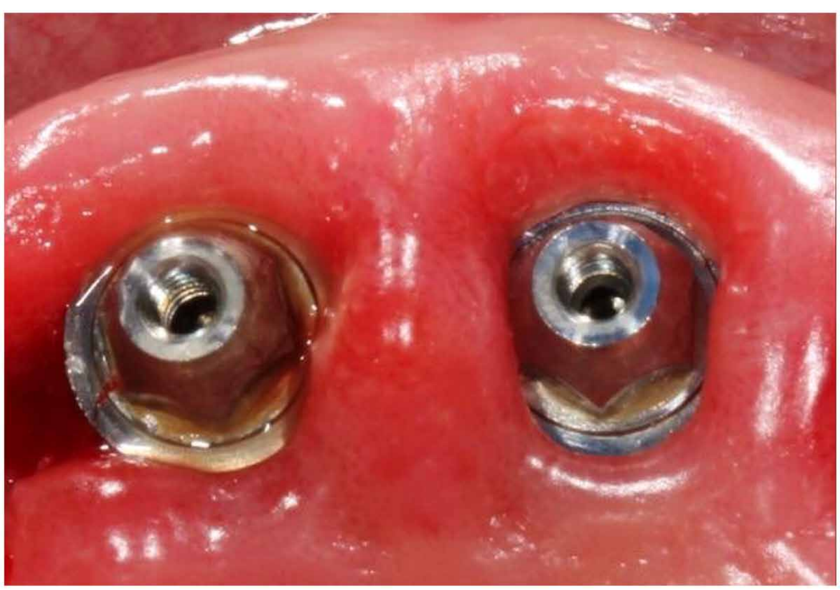


Figure 33c. The depth of the implant insertion combined with the thick tissue biotype give rise to a healthy peri-implant environment

Figure 34. The soft tissue dimensions around implants are based upon a consensus in the literature of 3 mm tissue thickness, 3 mm tissue height, and 3 mm width of the keratinized gingiva (Jung et al., 2000)

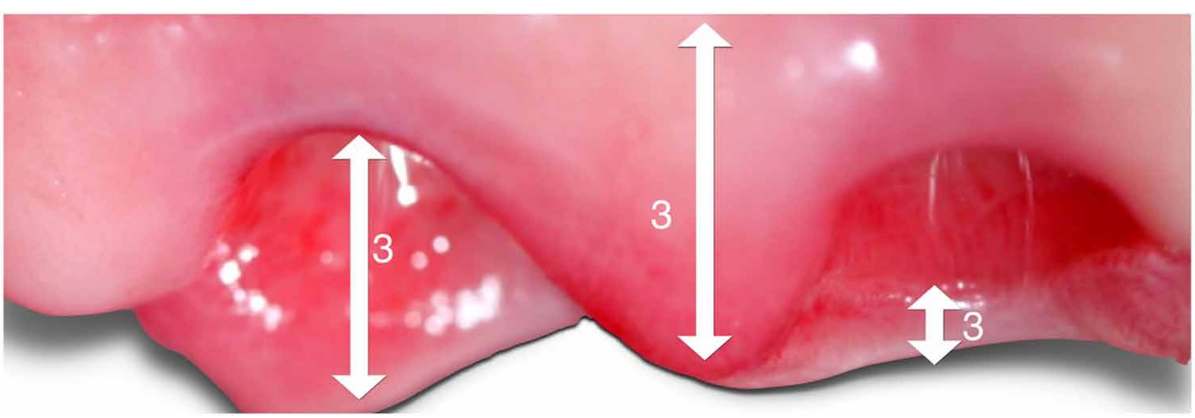


Figure 35a. The healed dimensions of the thickness and height of the keratinised tissue will conserve the underlying bone, thereby avoiding vertical and horizontal boney atrophy

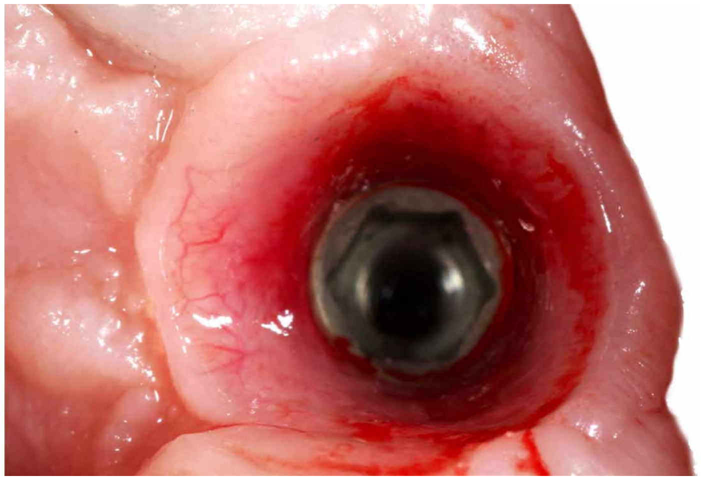


Figure 35b. The mirror image of Figure 35a showing the keratinised tissue that helps preserve the supportive bone

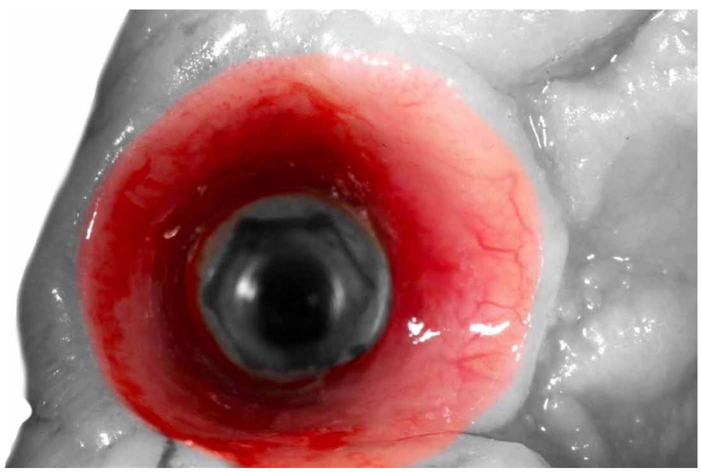


Figure 36. These dimensions and position of the tissues should be maintained and created independent of the implant design

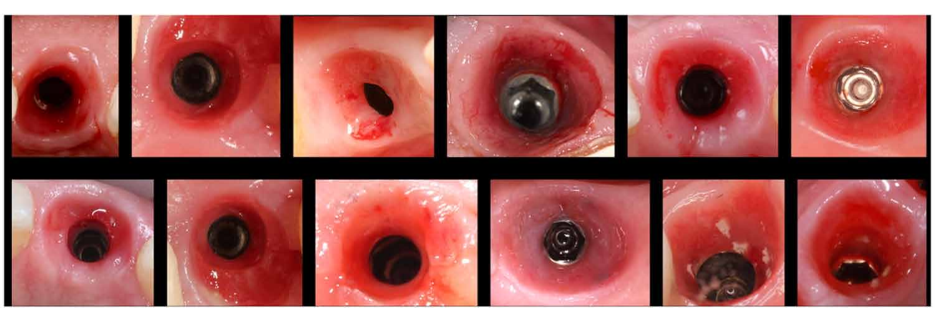


Figure 37a. The palatal view of the planned final abutments being created digitally, respecting the specific architecture of the emergence profile

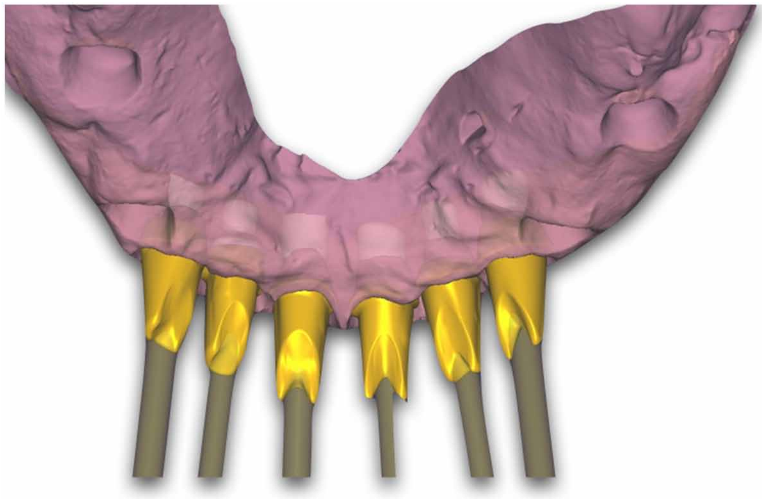


Figure 37b. The digital final abutments underlying the provisional rstoration template, to insure the abutment dimensions fit properly within the desired esthetic design

Figure 37c. The final abutments as designed within the planning software

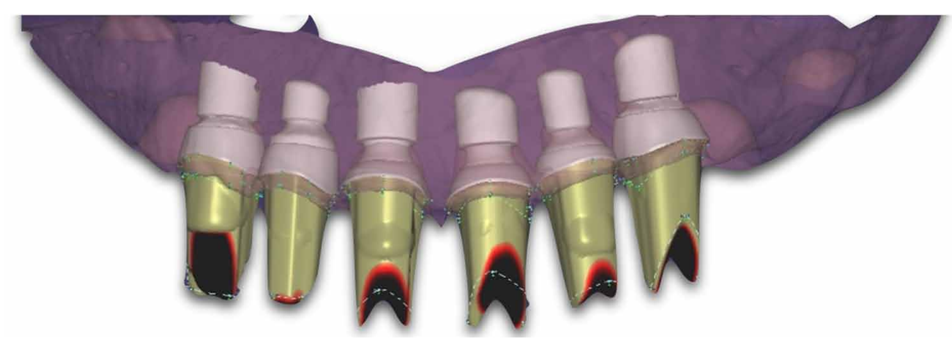


Figure 38. Each milled zirconia abutment is glued appropriately onto a titanium base (Multilink Automix, & Monobond Plus, Ivoclar Vivadent, Schaan, Lichtenstein)

Figure 39. The individual abutments seated back onto the analog cast

Figure 40. The maxillary crowns in place at the moment of cementation

Figure 41. The maxillary custom abutments seated intraorally, shown underneath and through the final crown's transparent external conours

Figure 42. The post insertion panoramic radiolograph illustrating all the digitally designed and installed implant components of the final restorations

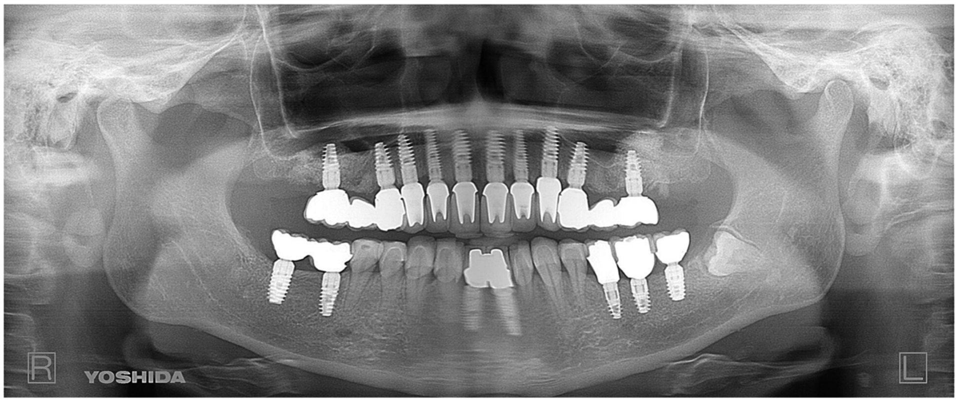
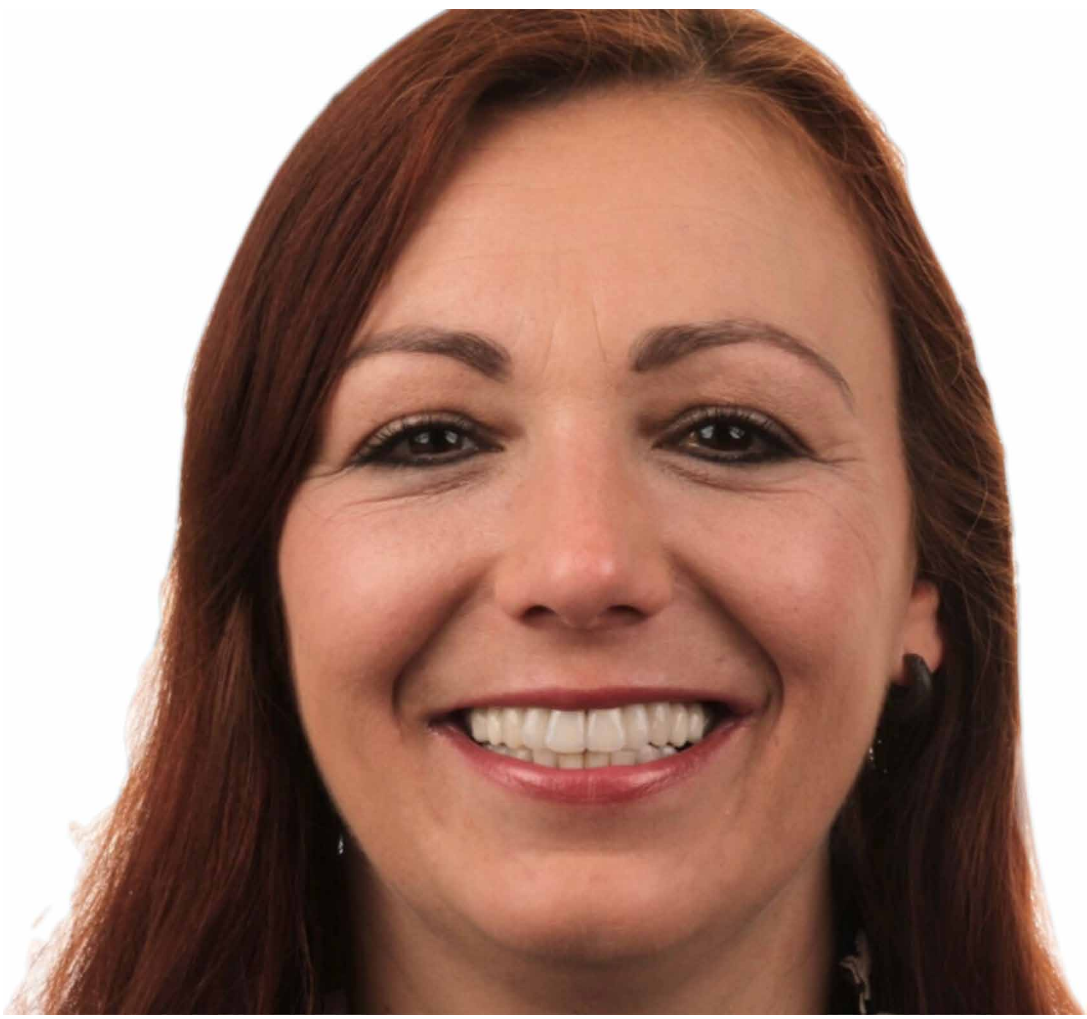


Figure 43. Once again the happy patient is smiling with her newly installed implant reconstruction



The main occlusal contacts will occur between the implants in both the maxilla and mandible. Implants do not have periodontal ligaments, so they have minimal resilience of 4 microns. The implants will occlude with teeth and implants so that means a movement of 10 to 33 Microns, hence why thin articulating paper (25 microns) is used. If there premature contacts, interferences or overloads, the implants will suffer through bone loss. A mutually protected occlusion has been considered the ideal occlusal design in full mouth implant rehabilitation (Hobo, 1989; Prashanti et al., 2008, Abichandani, et al., 2013; Verma et al., 2015)

Multi-bite registrations were recorded and adjusted in sequence, to reduce the closure forces on any overloaded implants and to centralize the COF within all the implants (44 - 50; the Final Restoration can be seen in Figures 51 - 53).

In full mouth implant prosthesis occlusal design, immediate posterior disclusion through reducing the Disclusion Time should be employed, (also through reducing the cuspid heights and inclination to < 15^0, because immediate posterior disclusion can prevent unnecessary muscle activity from applying excessive force to the implant prosthesis, that could harm the restoration or the supportive bone. In repeated studies Kerstein shows that the optimum disclusion time < 0.4 seconds, demonstrating how the muscle activity is kept low when measured with EMG (Kerstein, 1991; Kerstein & Radke, 2012; Kerstein & Radke, 2017). Generally, lateral excursive corrections will follow establishing the low-moderate closure force profile seen in Figures 49 and 50.

Figure 44. Initial Multi-bite registration of the installed reconstruction showing both intense and voluminous forces present on natural tooth #15 (pink, red, and orange columns; 33.1% of the Total Force), and implant warnings visible on the overloaded implants #s 13, 21, 24, and 26. Note the COF rests incorrectly on the right arch half due to the excessive forces on the #15, but there are more occluding teeth on the left arch half. The COF should always correctly sit on the side of the arch with more occluding units.

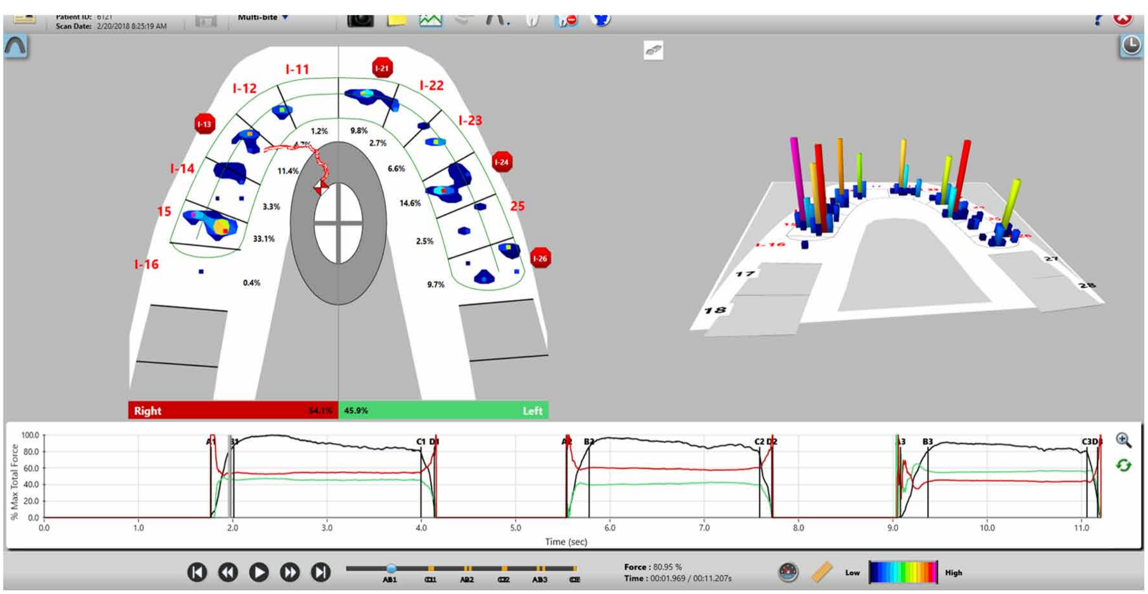


Figure 45. After 1 set of adjustments there are still 6 overloaded implants, in that tooth #15 has been reduced a small amount to 29.8% of the Total Force. This is typical of sequential T-Scan guided adjusting where a series of corrections are needed to improve a restoration's occlusal force profile. Note the COF starts on the right arch half, but then moves forward indicating there is an excessive anterior force rise in the middle of the closure on #s I-21 and I-22. Then later in the closure, the COF moves posteriorly and left because of the excessive force rise on tooth #15.

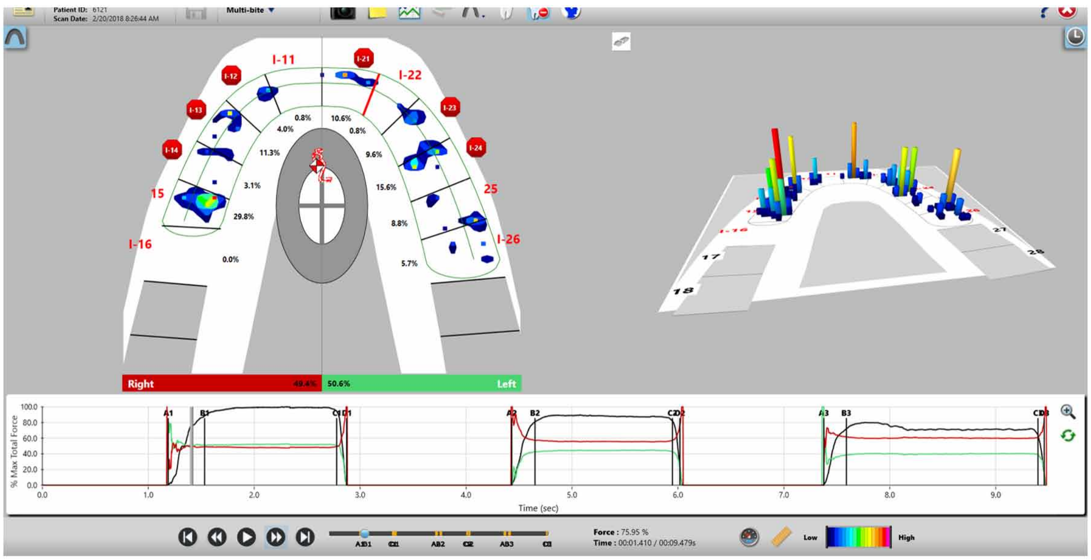


Figure 46. After 2 sets of adjustments, the occlusal contact forces are now more moderate (light green columns) throughout the implant restoration with overload visible on #I-24 (pink and yellow columns). Only 2 implants show warnings (I-24 and I-12), indicating an improvement from the force profile visible in Figure 44. Tooth #15 now comprises only 9.2% of the Total Force, and the COF now correctly sits on the right arch half, where there are more occlusal units, as I-16 has no mandibular opposing counterpart.

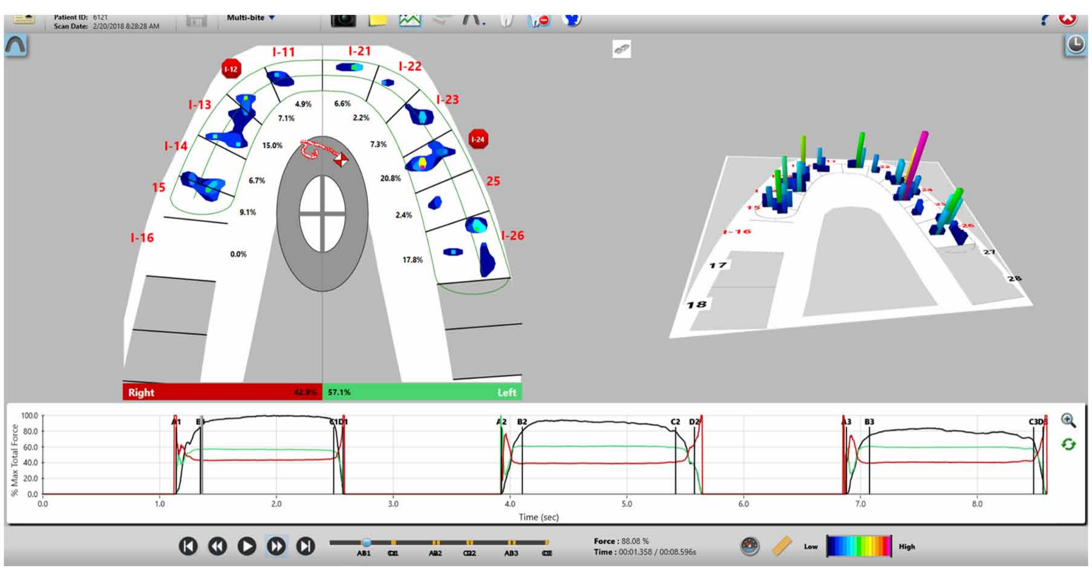


Figure 47. Following the 3rd set of T-Scan guided occlusal corrections made to the force profule of the data shown in Figure 46, only #1-24 implant is overloaded, while the other implants and teeth all demonstrate moderate forces.

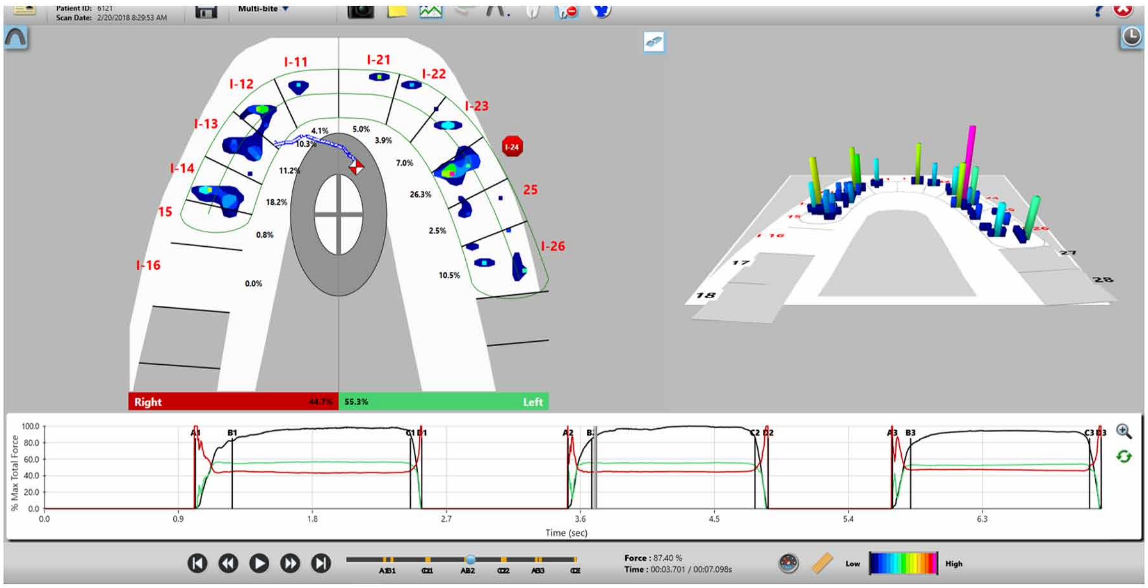


Figure 48. The delivered closure result with no implants overloaded and all implant warnings eliminated from the corrections made in sequence to each T-Scan data set. Note that in the T-scan frame displayed at 96.06% Total Force, no more pink red or yellow columns are visible, with only the I-12 needing some force reduction. When compared to Figure 44 in which the displayed T-Scan frame is at 80.95% Total Force (with many red, pink, yellow and orange columns visible), after all T-Scan guided occlusal corrections, the patient can close firmer to near maximal MIP without overloading any implants.

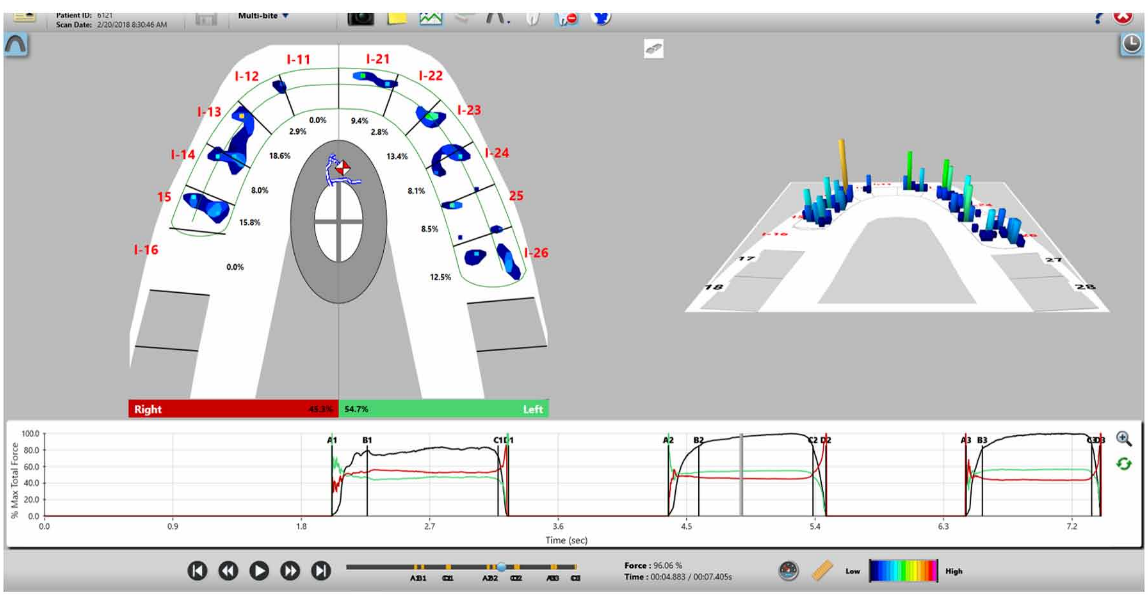
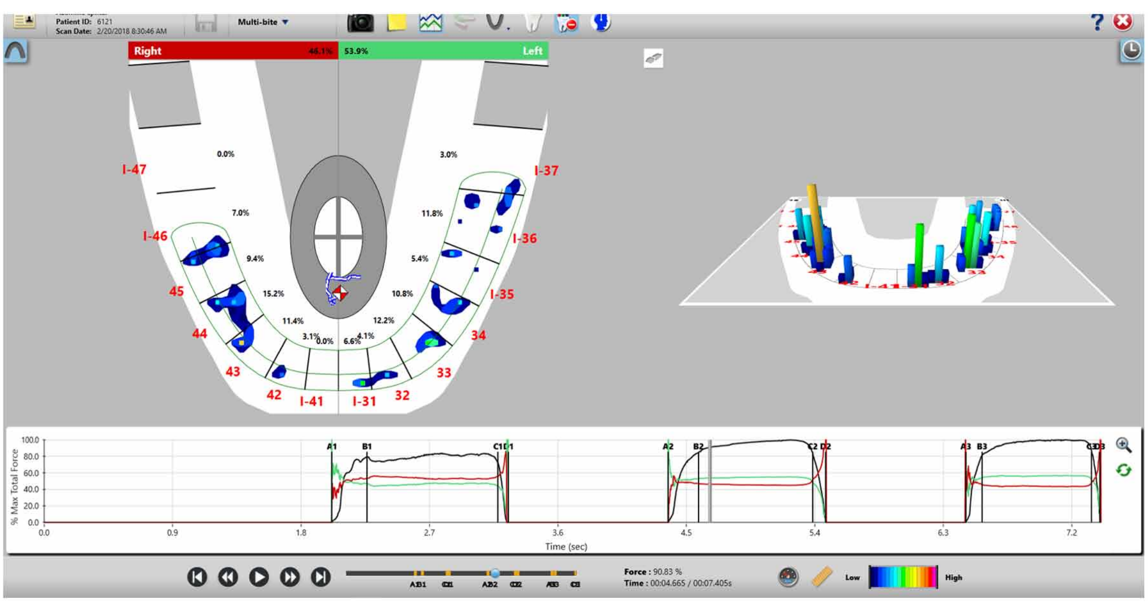


Figure 49. The same data in Figure 48 but with the Quadrant Division line purposefully placed at the distal of the #s15 and 25, to illustrate the arch half force % balance when equal numbers of occluding teeth on each arch half are involved in the computation. The #I-26 data is excluded, being placed behind the quadrant division, as the #16 has no occlusal contact. The right anterior red quadrant (data anterior of the dividing line) = 45.3%, with the left anterior green quadrant (the data anterior to the dividing line) = 42.1%, resulting in only a 3.2% force imbalance. This near-equality of the arch half force percentages anterior to the Quadrant Division line, is why the COF stays near the middle of the COF target during the patient's entire closure into MIP.

Figure 50. The mandibular arch showing the final installed force profile of the patient closing into MIP with no implant warnings remaining



Long Term Maintenance

A long-term guarantee is offered to these reconstructed patients of 15 - 20 years, which involves the patients being recalled every 4 months for control, professional cleaning, re-motivation, and yearly laser induced photodynamic decontamination of the sulcus of the teeth and implants (Sculean, et al., 2013, Deppe, et al., 2013). Each recalled patient also undergoes a digital occlusal adjustment with the T-Scan 10.

The 1-year computer-guided occlusal recall visit of the presented case, is described below in a series of T-Scan 10 data sets superimposed over the digital scan of the implant reconstruction, along with their accompanying clinical images. The occlusal force and timing issues captured by the T-Scan recordings, will be explained for the reader in the Figure captions. Initially, MIP closure corrective adjustments were performed (Figures 54-58), which were followed by right, left, and protrusive excursive corrections (Figures 59-63). Each excursion is illustrated in 3 frames to detail the progression from excursive commencement through to just prior to posterior disclusion. The excursive figures illustrate that no

Figure 51. The smiling patient 1 year post implant reconstruction

Figure 52. The 1 year follow up panoramic radiograph showing the restorations in place and all implants well embedded in bone

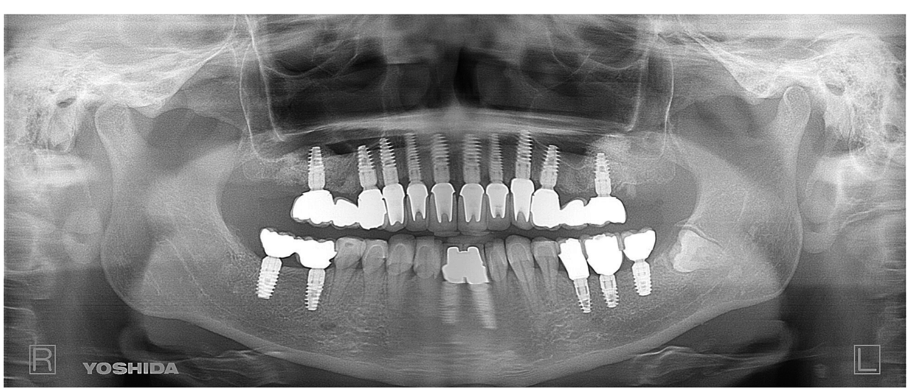


Figure 53. The tissue healing of the maxillary restoration after 1 year, is ideal

mandibular excursion has 0.00 second-long Disclusion Time, such that both healthy and unhealthy disclusion occurs in a time range that always includes some opposing posterior occlusal surface frictional contact engagement.

1-Year MIP Closure Contact Corrections

The below clinical photograph, and the others that follow, which illustrate the 1-year correction adjustment sequence, are oriented so that the crowns match the T-Scan virtual dental arch. Looking at the photograph below (Figure 54b),

- The implant crowns visible on the left arch-half of the picture are the right teeth #s I-16 - I-11
- The implant crowns visible on the right arch-half of the picture, are the left teeth #s I-26 - I-21.

This presentation helps the reader to compare the articulating ink markings to the matching force profile and is shown in all of the following T-Scan data figures.

Figure 54a. Initial Multi-bite closures into MIP after 1 year. Note there are 6 forceful contacts present, and 3 overloaded implants that set off implant warnings (#s I-21, I-24, and I-26).

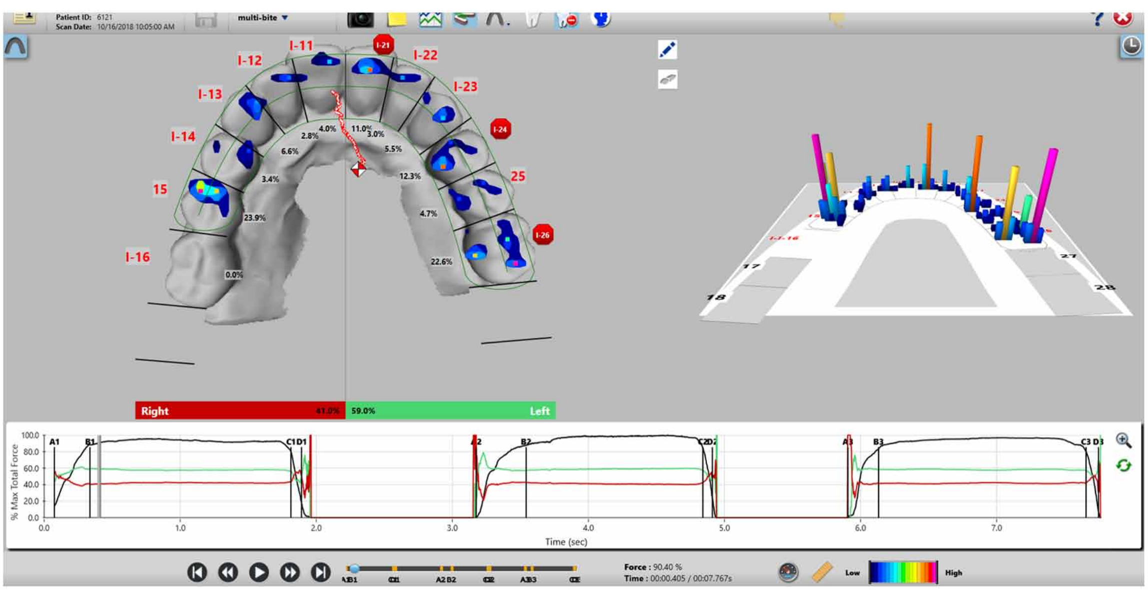


Figure 54b. The pre-operative articulating paper markings of the forceful, overloaded contacts seen in Figure 54a, where the paper markings show more area of contact on the left side (59% left - 41% right). The earliest contacts start in the frontal area, then moves slowly to the center. The 2 moderately forceful contacts present on #I-14 (yellow columns on the distolingual and mesiobuccal), and the pink and red columns present on and #s I-23 and I-24, all need to be adjusted, being much stronger in force level than the low force (blue and light blue columns) contact points.

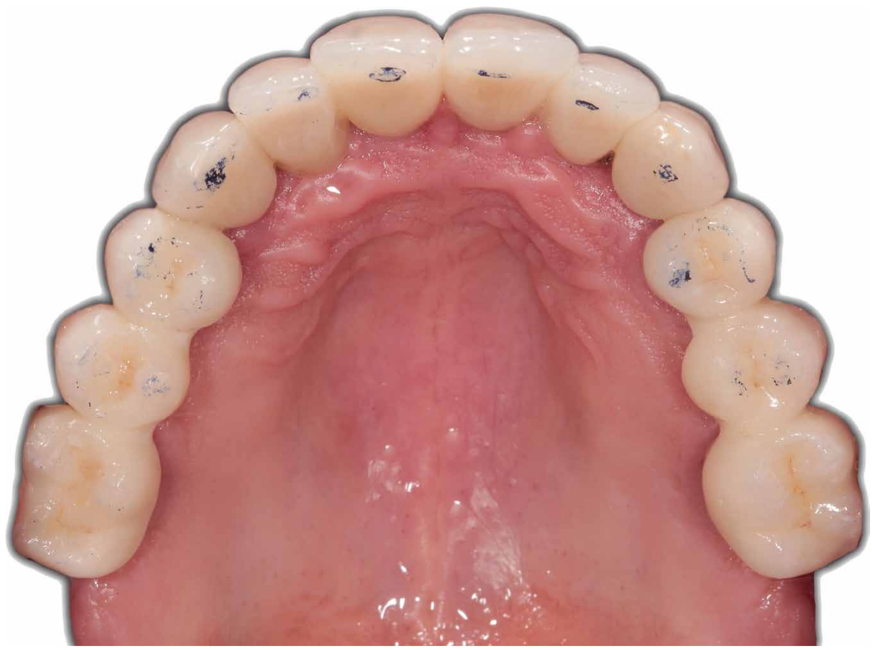


Figure 55. After 1 set of T-Scan guided closure adjustments to the 6 forceful contacts, at MIP there remains 3 forceful closure contacts present, with 3 implants still showing overload warnings (#s I-14, I-23, and I-24)

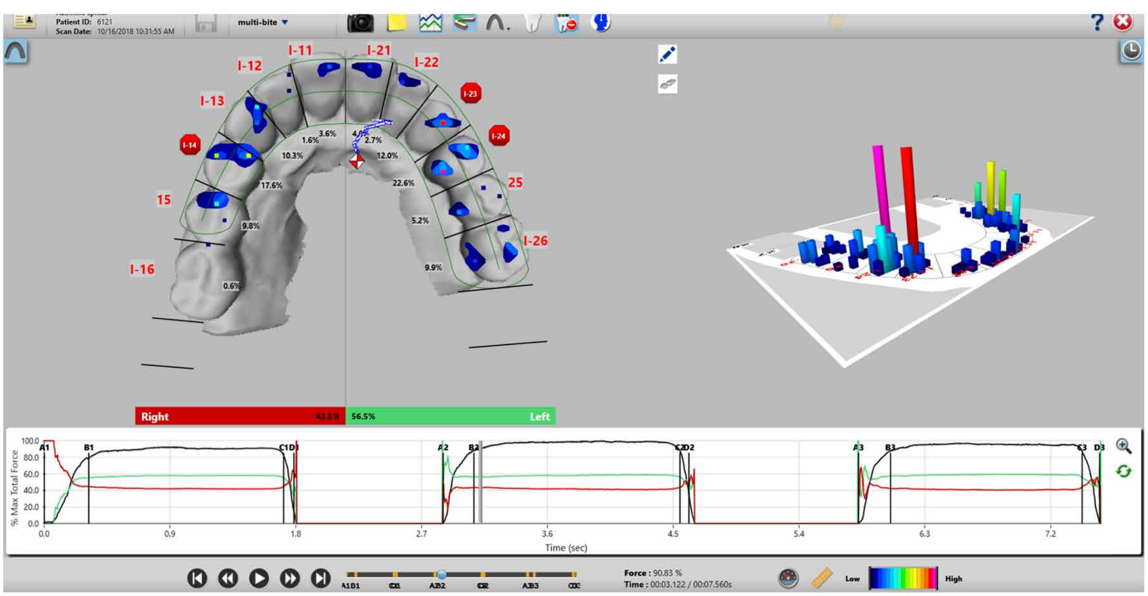


Figure 56. After 2 T-Scan guided closure adjustments, some moderate anterior pressure developed in MIP, denoted by the light-blue, light-green, and yellow columns, present anteriorly from #s I-13 to I-23. Also, the COF icon stays near to anterior teeth instead of moving posteriorly), which is marker for building anterior pressure. Most forces throughout the implant prosthesis are lessened compared to those in Figure 54a, as only 2 implants show overload warnings (#s I-21 and I-23)

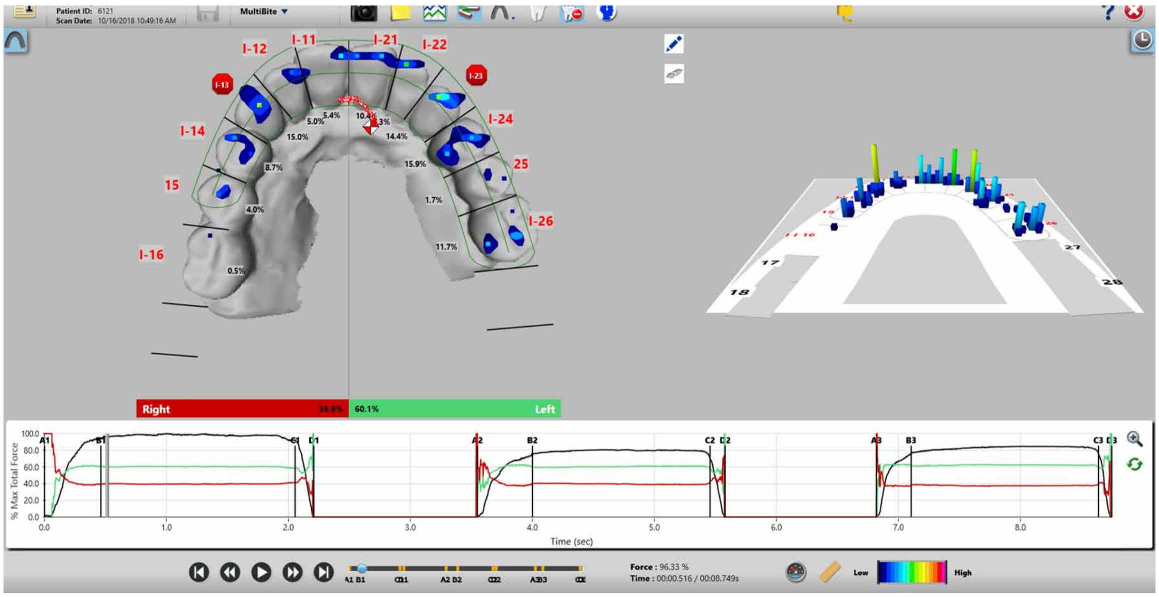


Figure 57. After 3 T-Scan guided closure adjustment sequences, the anterior pressure is lessened but still present, as there are remaining light-blue, light-green, and yellow columns. The COF is slightly more posterior, but is still favouring the 6 anterior units, instead of sitting more in the premolar, mid-arch position. However, now only 1 implant (#I-21) remains overloaded

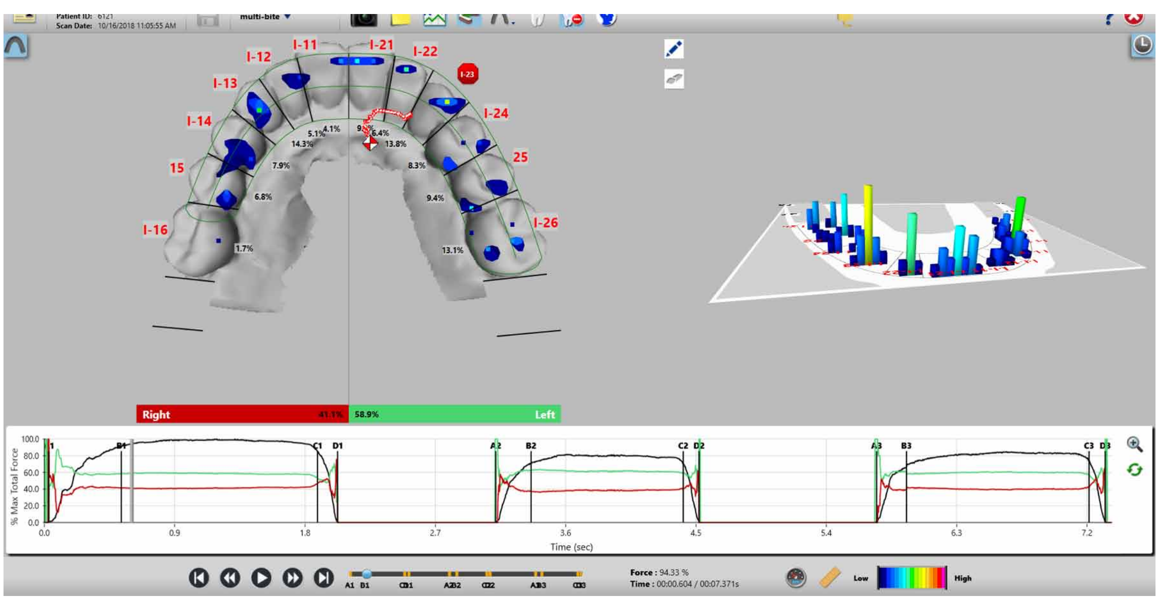


Figure 58a. After 4 adjustments the MIP closure is balanced, with all contacts demonstrating a low force profile (only dark-blue and light-blue columns present). There are no implant warnings remaining. There is a slight left side imbalance (4.9%), because the #1-26 has more force than its counterpart #I-16. Notice the COF is sitting just left of the arch midline, between the 1st premolars, having moved posteriorly after the anterior pressure was relieved by the targeted, T-Scan guided adjustment protocol.

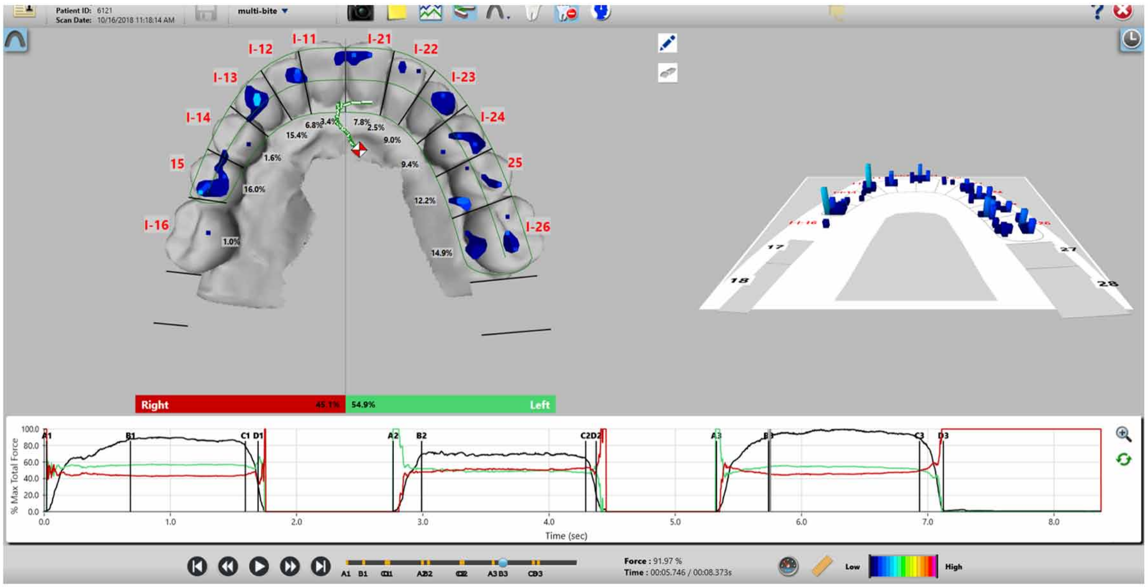
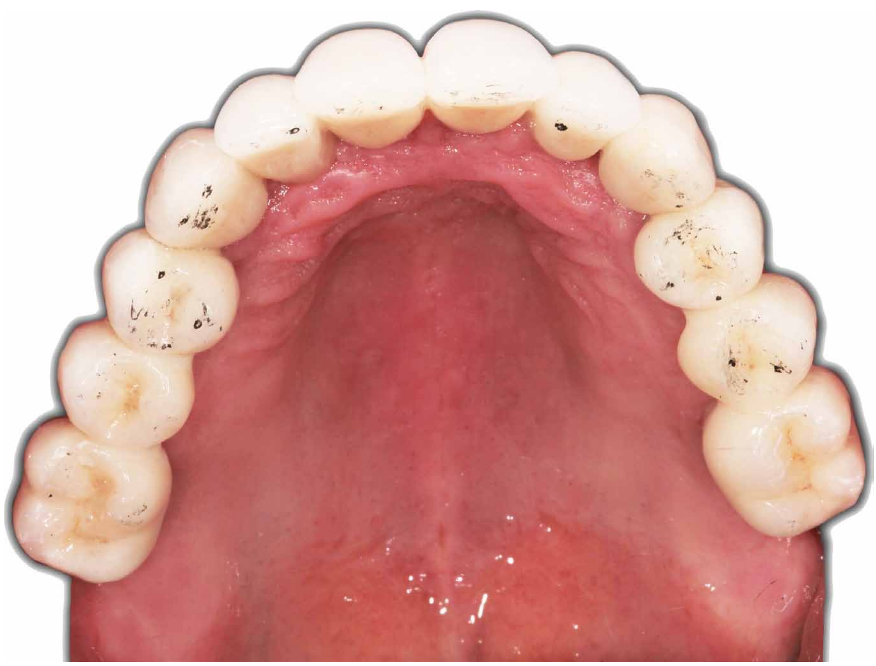


Figure 58b. The post T-Scan guided, closure adjustment articulating paper markings. Note that the repartition of the paper ink markings, representing that the contact points appear to be more equal. This corresponds to the repartition of how the T-Scan sensor showed the low force contact distribution.



1-Year Left Excursive Contact Corrections

See Figures 59-60.

Figure 59a. The left lateral recording at C, prior to the excursion commencing. The DT is prolonged = 1.43 sec.

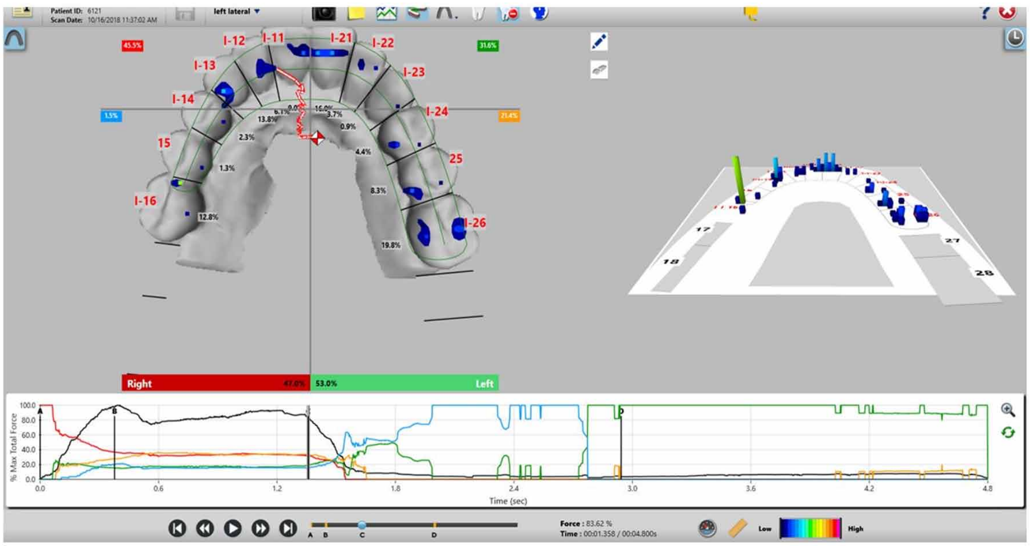


Figure 59b. The left lateral 0.207 seconds into the middle of excursion, when #16 balancing contact worsens in force level as the patient begins moving left. The prosthetic anterior guidance surfaces on the #23 are not effective at discluding the balancing side. Note how the blue posterior right quadrant line in the Force vs. Time Graph rises, indicating the right posterior quadrant controlled this excursion. Also note that the COF moves posteriorly right towards #16, instead of moving anteriorly left, towards the #I-23.

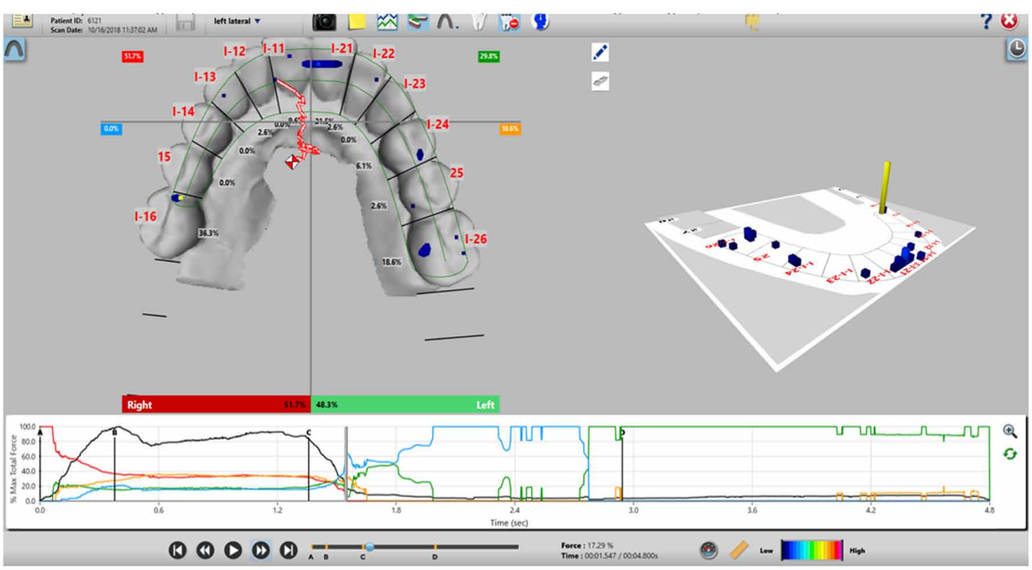


Figure 59c. Late in the left lateral excursion with #16 balancing contact discluding most of the working side contacts. The prosthetic anterior guidance surfaces in the #I-23 area, aren't capable of discluding the #16. The preoperative left excursive DT =1.43 sec

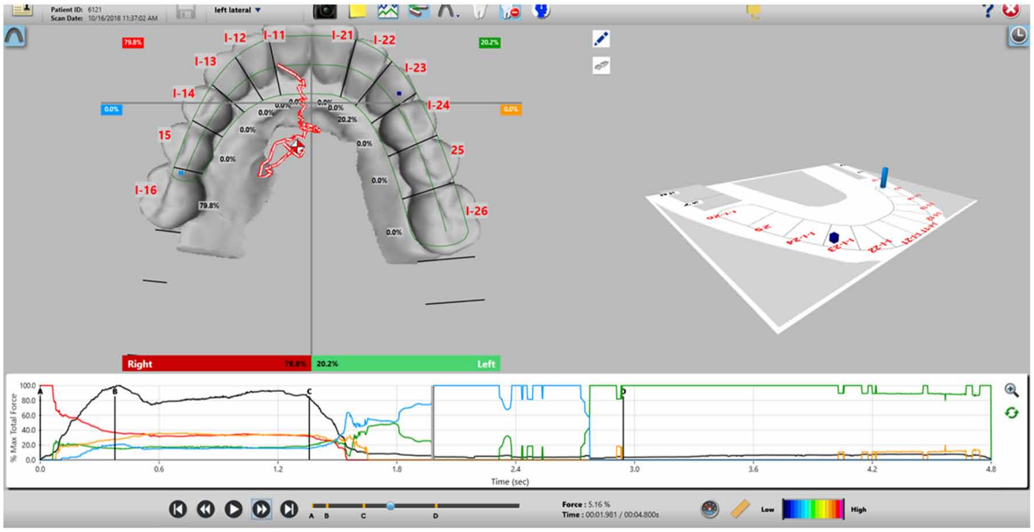


Figure 59d. The preoperative left lateral articulating paper markings There is an equal distribution of the ink markings when the patient closed into MIP. The lateral excursion is guided by the #I-23 canine crown (denoted by the strong black mark), which is unable to disclude #15 at the palatal-occlusal cuspal incline, where there are black ink markings lining the slope from the mesial, up across the palatal cusp, and down to the distal marginal ridge.

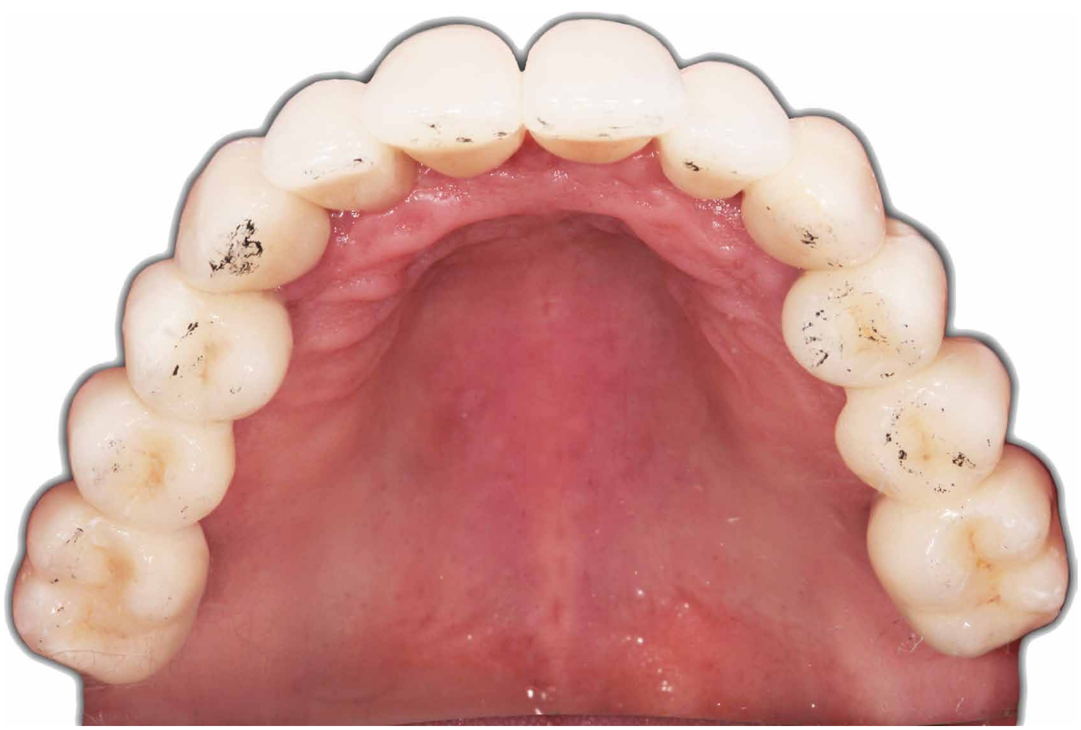


Figure 60a. Early in left lateral excursion after T-Scan guided excursive corrections. The prosthetic anterior guidance surfaces #I-22, and #I-23 begin to disclude #15 and #I-16. The Disclusion Time is 86% shorter than pre-correction. The new DT= 0.20 seconds. Note in the MIP closure period between B-C, the patient released her intercuspated occlusion allowing forces to drop (at 0.6 seconds), which caused the Total Force line to drop, as well. She then re-squeezed her teeth back together into full contact, just before beginning the excursion at C (where the Total Force line rises back up to the top of the Force vs. Time Graph).

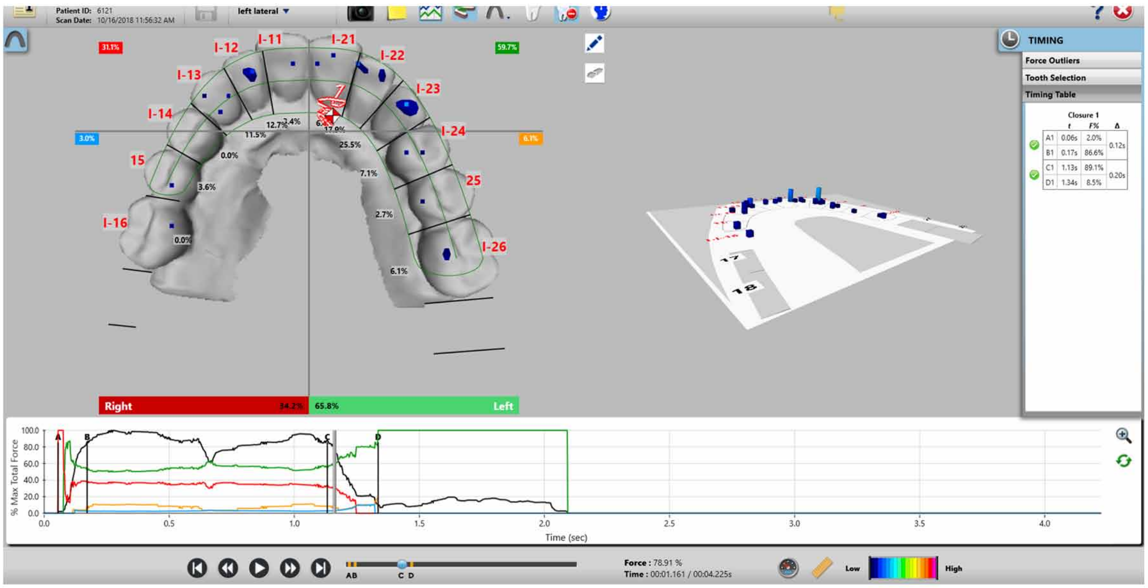


Figure 60b. Later in the left lateral excursion, just prior to complete posterior disclusion. #I-26 is the last remaining non-working side interfering contact, after which disclusion occurs. The DT = 0.20 sec

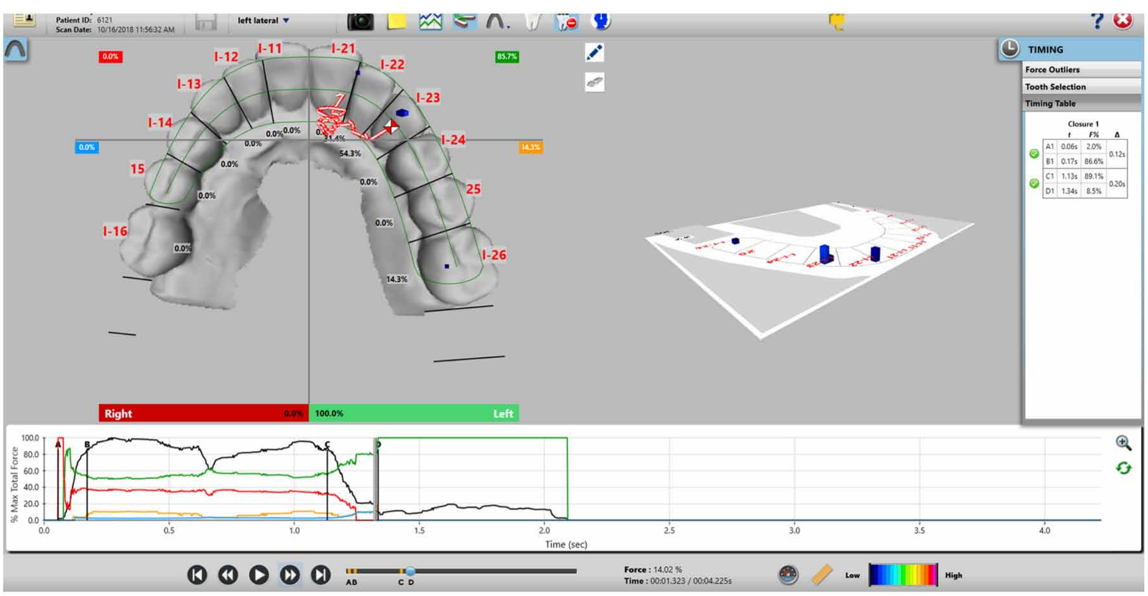


Figure 60c. Complete posterior disclusion achieved bilaterally by #sI-21, I-22, and I-23, in 0.20 seconds

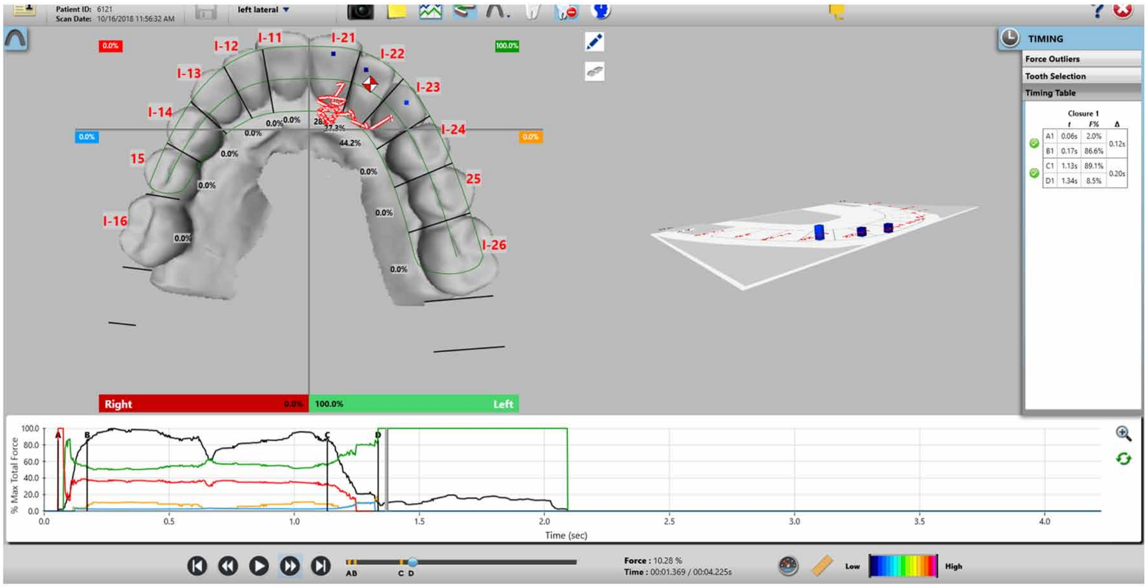


Figure 60d. The post T-Scan guided, corrected left lateral paper markings. There is a clean movement guided by #I-23, with no paper marks visible on the contralateral (balancing) side. The left lateral T-Scan data in Figure 60c shows this clean movement, by how the COF trajectory moves towards #I-23 without hesitation.

1-Year Right Excursive Contact Corrections

See Figures 61-62.

Figure 61a. This a very good example of the patient "letting go" of their MIP intercuspation, resulting in their closure forces dropping to 60%, before the patient makes a right excursion at Line C. Note how the Total Force line drops from the top of the graph well before C, at 2.4 seconds. In these "out of MIP" weak, excursive recordings, the recorded DT is always less what than the actual DT would be, if the excursion was made from complete MIP intercuspation. Because the patient starts the excursion already out of full contact, the recorded DT is shortened. Early in this right excursion there are prolonged low force contacts present on #s I-24 and I-26. Had the patient held MIP fully intercuspated until C, these interferences would be longer in time, and more forceful. The recorded DT = 0.50 seconds.

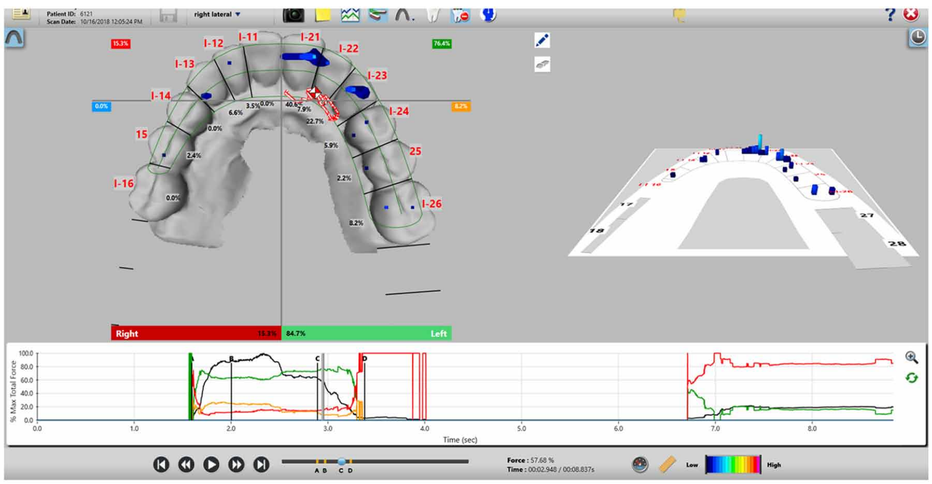


Figure 61b. Mid right excursion, the anterior guidance is shared with the left anterior crowns #s I-22, and I-23, while the #I-13 stays low force, before lifting #s I-24 and I-26 apart on the left balancing side

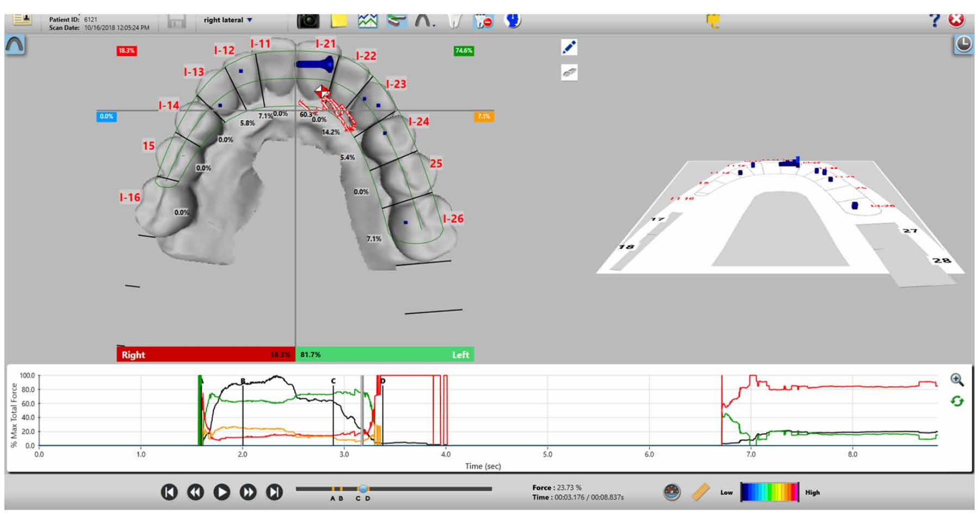


Figure 61c. At this late moment in the right excursive movement, the right excursion still involves #I-26. Posterior disclusion is then achieved shortly, thereafter.

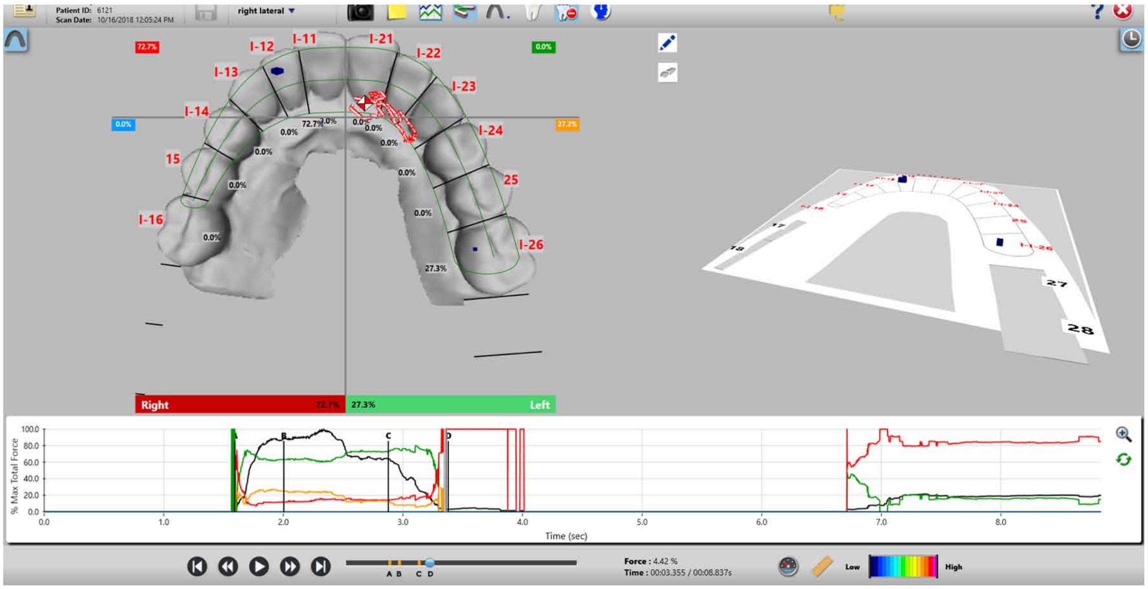


Figure 62a. Very early in the right lateral movement following T-Scan guided right excursive corrections. There are low force working and balancing contacts still present, even with a short DT = 0.29 seconds. Note that the patient began to let go from MIP at 1.6 seconds (The Total Force line starts to gradually drops from 100% to 74%, in the Force vs. Time graph approaching Line C), before the patient beginning the excursion at Line C. The Total Force line also drops at excursive commencement as the patient markedly disarticulates their posterior teeth. The 0.29 second DT is likely slightly shorter than if the patient began the excursion from MIP.

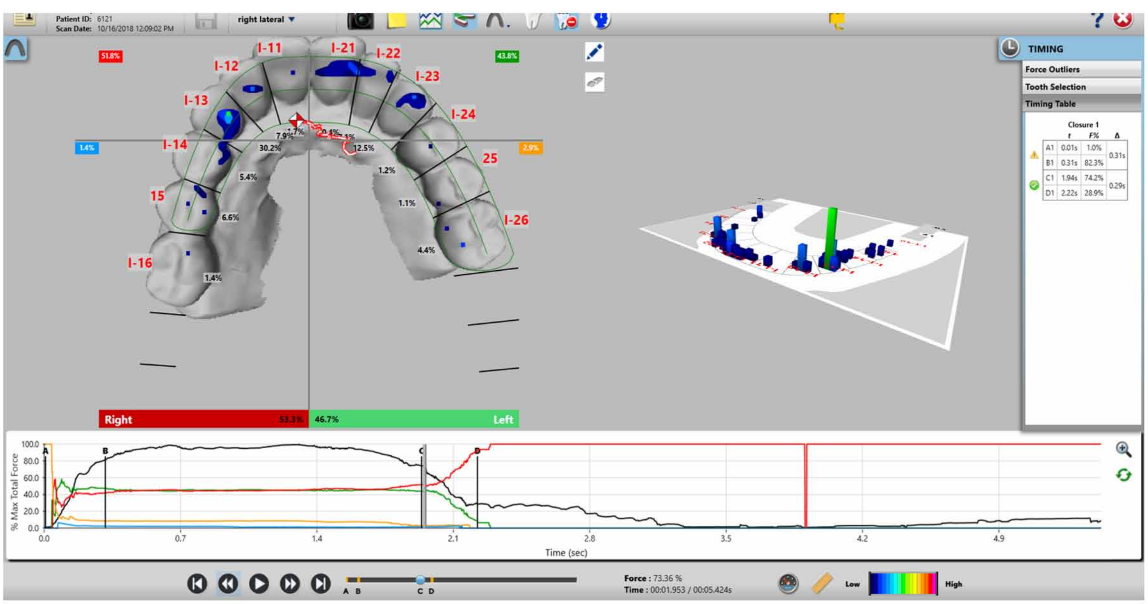


Figure 62b. 0.22 seconds into the corrected right lateral excursion. Most of the early low force working and balancing contacts have dissipated, as #I-13 takes over the lateral movement

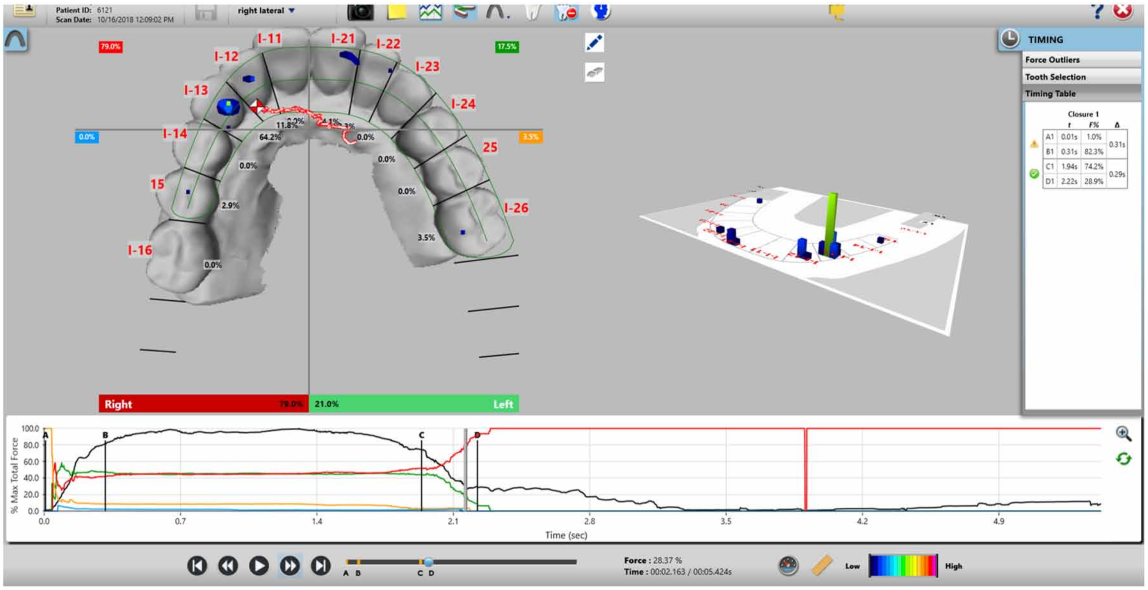


Figure 62c. The same right lateral movement just prior to complete posterior disclusion. #15 lingual is the last remaining working side interfering contact. The DT = 0.29 seconds

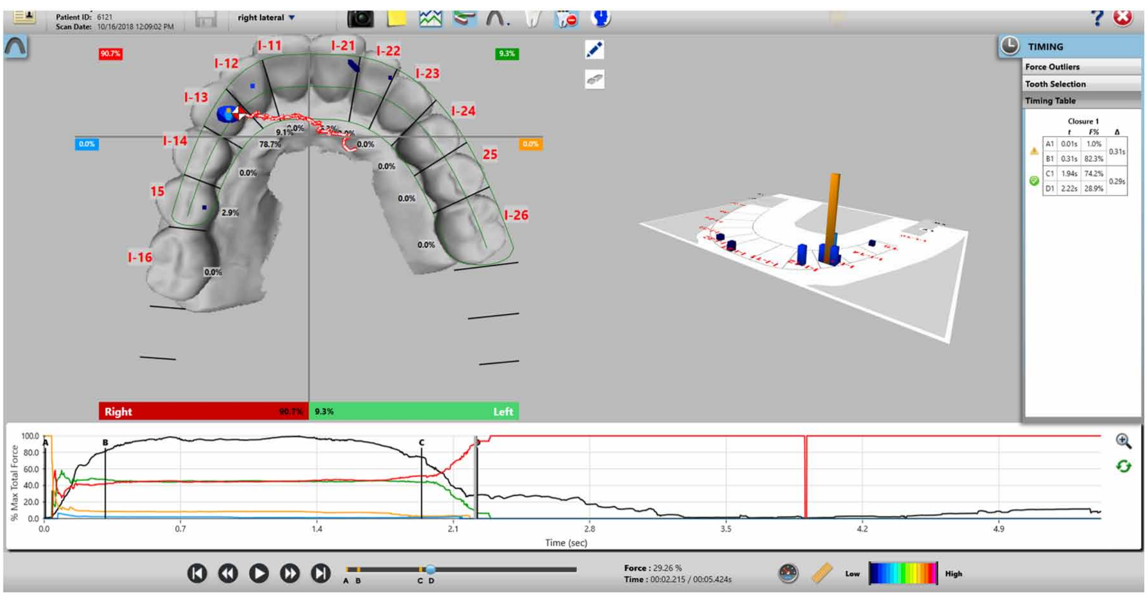
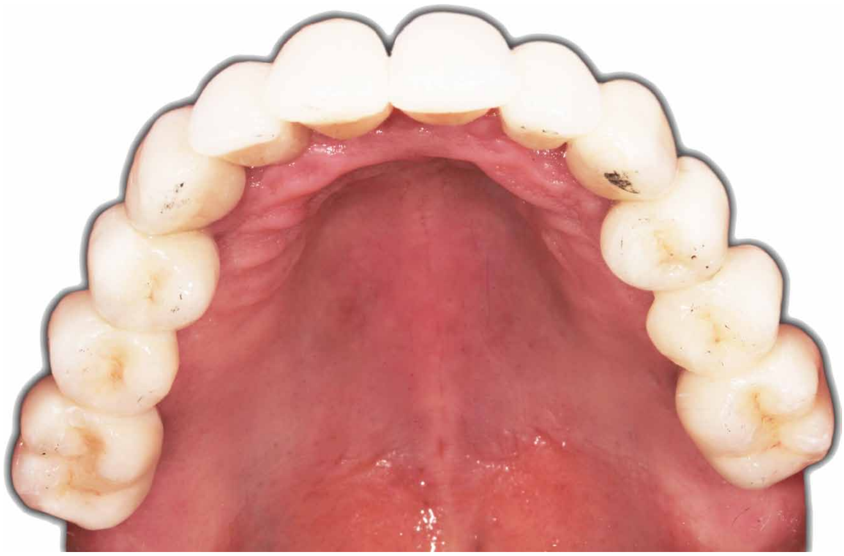


Figure 62d. The post T-Scan guided corrected, right lateral articulating paper markings. This canine-guided movement made a dark blue ink mark on the palatal incline of the cuspid. But no other marks are very visible, indicating posterior disclusion does occur.



1-Year Protrusive Excursive T-Scan 10 Data

See Figures 63a - d.

Figure 63a. Early in protrusion, the anterior guidance forces slightly increase on #s I-23, I-21, and I-13, while posterior contact persists. The DT = 0.21 seconds, indicating no corrective adjustments appear necessary, because the protrusive prosthetic guidance surfaces effectively disclude the posterior teeth

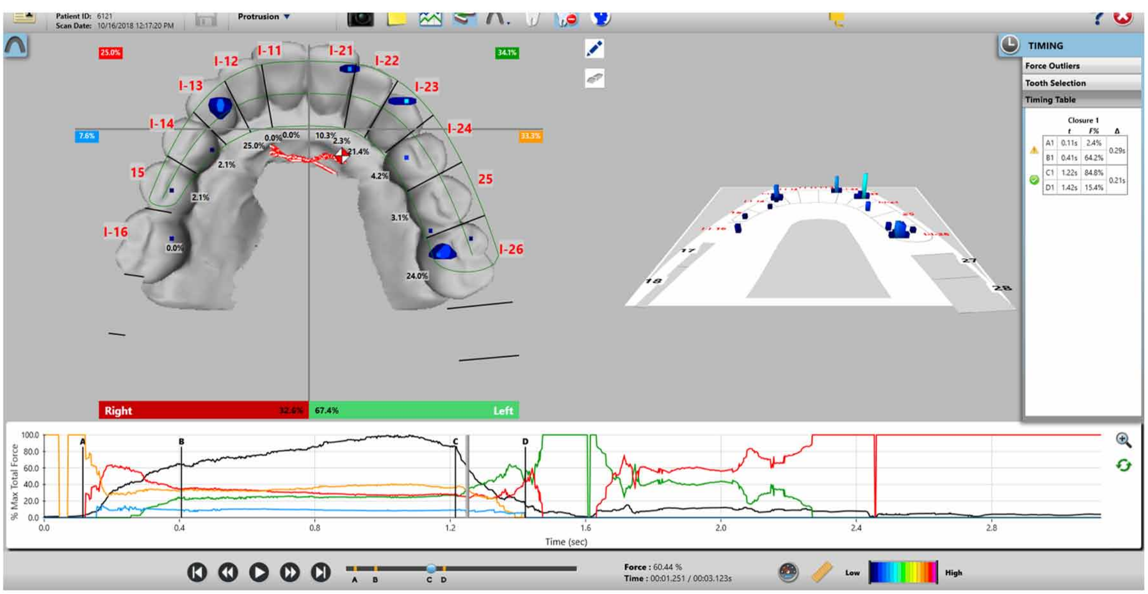


Figure 63b. Later in protrusion with the last posterior contacts still present, # I-21 is taking momentary excursive control, demonstrating an increase in its protrusive force level

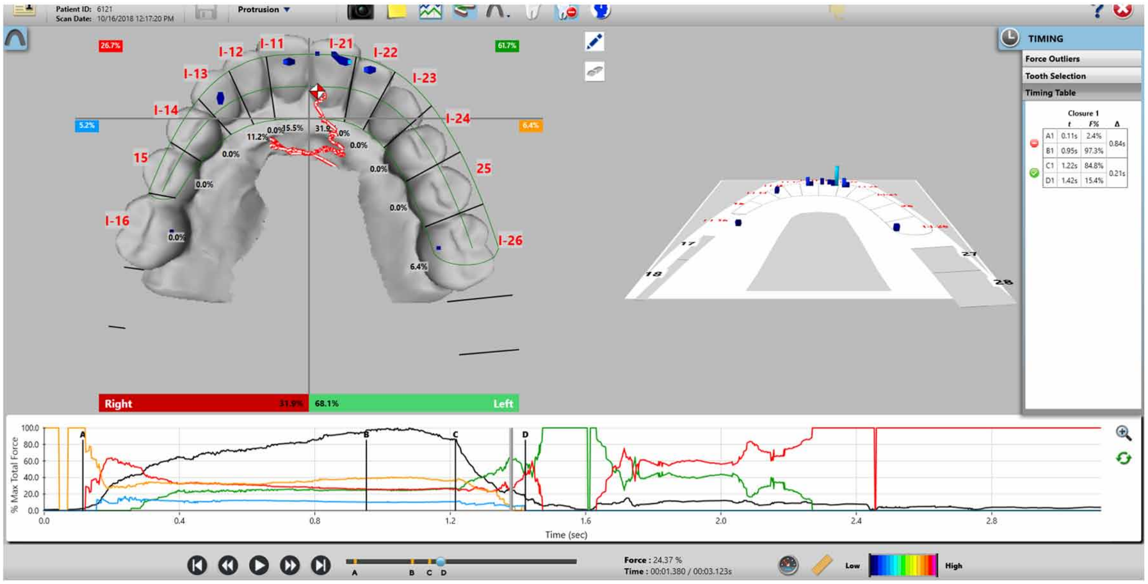


Figure 63c. Just prior to the last remaining posterior contact (#I-16) discluding, #s I-11, I-21 and I-22 have shared force levels. Note how the COF trajectory moves anteriorly between #s I-11 and I-12. The protrusive DT = 0.21 seconds

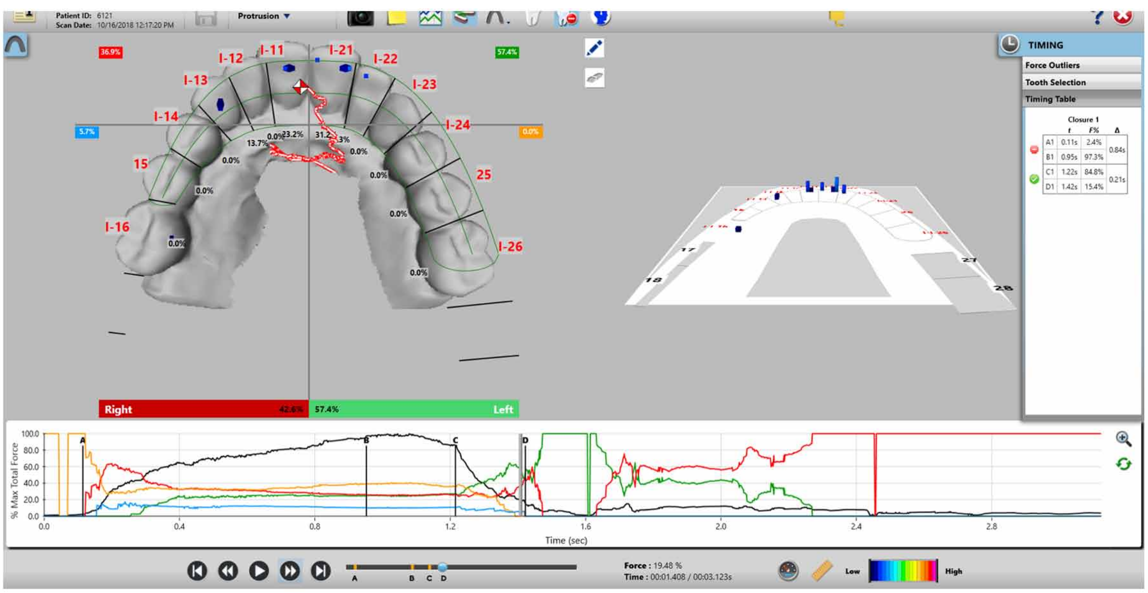
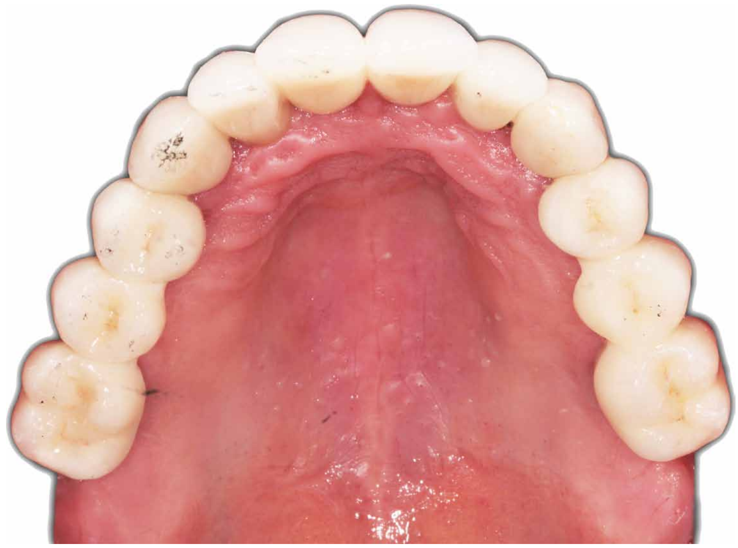


Figure 63d. The post T-Scan guided corrected protrusive articulating paper markings. Note how the # I-23 linear ink mark, corresponds to #I-23 crown rising in force early in the excursion (Figure 63a; light-green column). Later in the movement when only the incisors control protrusion, blue ink markings appear on the incisal edges of the implant crowns #s I-11, I-12, and I-22.



SOLUTIONS AND RECOMMENDATIONS

The occlusal solution and recommended protocol for implant-supported, or mixed implant and natural teeth combined reconstructions, is for clinicians to make a precise, digital occlusal registration with the T-Scan technology, followed by control of the occlusion and function using the T-Scan to guide the measured occlusal adjustments. As such, it is this author's recommendation that the T-Scan technology should be a regular component in the Digital Workflow of full arch reconstructions performed on implants and teeth.

The following points within the Digital Workflow are when the T-Scan technology should be instituted:

1. **Preoperative Digital Occlusal Analysis**: A digital occlusal registration and T-Scan guided corrective adjustments should be made of the pretreatment occlusion, to be the reference condition for the digital or analog wax up. In the case of TMD muscular pathology, Electromyography (EMG) should also be recorded to monitor excess muscle activity, as part of making a complete, functional diagnosis. Only after healthy and stable occlusion is established, should implant treatment be initiated.
2. **Provisional Occlusal Force Control**: Once the implants have been placed, a digital occlusal registration and corrective adjustments of the immediate provisional restoration should be performed. This helps control the occlusal forces during the early, osseointegration healing period.

It is important to respect the rules of immediate loading, by splinting all implants together with the full arch immediate provisional, and allow for at most, 150 microns of implant movement. This limited implant movement ensures implant osseointegration to the bone will occur (Misch, et al., 2008).

3. **Create an Optimal Provisional Occlusal Force and Timing Environment**: Minimal movement of the splinted implants can be established by the provisional restoration having:
   a. A measurably balanced occlusion, with a widespread low force profile (Figure 58a),
   b. Cuspid lingual inclines of less than 15^0
   c. No prolonged excursive interferences present in lateral excursions

   Once the provisional occlusion is correctly adjusted, the esthetic contours, the occlusal surface topography, and the anterior palatal morphologies, will all be transposed into the final restoration after osseointegration has completed.
4. **Occlusal Force Finalization of the New Implant Restoration**: The occlusal registration and adjustment of the final restoration is always required, no matter how precise is the transposition of the occlusal situation and contacts, from the provisional to the final restoration. These T-Scan guided insertion occlusal adjustments correct for the following Digital Workflow spatial errors:
   a. Milling procedure inaccuracies range from 30-60 microns (Corinna, Eva, & Kirsch, 2016).
   b. Cementation errors result from differences in the applied finger pressure per crown, when the crowns are cemented onto the implants (Zortuk, et al., 2010).
   c. Screw retained reconstructions demonstrate differences in screw depth, from variable screw-tightening force being applied per implant.
5. **Long-Term Occlusal Force Control**: T-Scan 10-based occlusal force control and adjustments should be accomplished at least once per year, together with supportive tissue biofilm debridement and decontamination. These are the main tools of long-term implant prosthetic maintenance. Together, they will enhance occlusal material survivability, implant part component survivability, and promote supportive tissue health.

Annual digital occlusal maintenance recall is a necessity, because over time, teeth can slightly move and change position in response to the repetitive and cyclically applied, occlusal forces. Teeth may also elongate when attempting to make contact with their antagonist tooth. These factors cause changes in the occlusal environment, which if not properly mitigated through corrective adjustments, can lead to supportive bone loss, and later to peri-implantitis.

FUTURE RESEARCH DIRECTIONS

To develop the routine and effective superimposition of the scanned virtual dental arches within the T-Scan software, while using the T-Scan's force and timing data to control the digital prostheses occlusal surface design contours.

Studies that can help determine how to integrate the precise, digital occlusal condition into the restorative and implant prosthesis planning software, to use the force and timing data with the virtual articulator. This could help to markedly lessen the need for mechanical occlusal adjustments made in the mouth to the ceramic or zirconia restorations, which are contraindicated when utilizing these materials.

Studies implementing EMG both in diagnosis and during occlusal adjustment procedures could help validate EMG's routine clinical use. These types of studies could improve the way dentists diagnose a muscular problem, while protecting the muscles from stress, high tension, and pain, as a consequence of a potential TMJ disorder.

CONCLUSION

T-Scan 10 is an essential component of a modern dental practice's Digital Workflow. It is the most precise, digital occlusal measurement tool available to clinicians, for determining and predictably adjusting the occlusal condition to very high tolerances (20-25 microns). Moreover, the T-Scan is vital for the long-term maintenance of restorations on both teeth and implants, because it protects the supportive bone and soft tissue structures, preventing bone loss, soft tissue recession and inflammation, muscular TMD disorders, ceramic chipping, screw loosening, and implant component material fractures.

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REFERENCES

Abichandani, S., Bhojaraju, N., Guttal, S., & Srilakshmi, J. (2013). Implant protected occlusion: A comprehensive review. *European Journal of Prosthodontics*, *1*(2), 29. doi:10.4103/2347-4610.116588

Al Rifaiy, M., Qutub, O., Alasqah, M., Al-Sowygh, Z., Mokeem, S., & Alrahlah, A. (2018). Effectiveness of adjunctive antimicrobial photodynamic therapy in reducing peri -implant inflammatory response in individuals vaping electronic cigarettes: A randomized controlled clinical trial. *Photodiagnosis and Photodynamic Therapy*, *22*, 132–136. doi:10.1016/j.pdpdt.2018.03.002 PMID:29550362

Carey, J. P., Craig, M., Kerstein, R. B., & Radke, J. (2007). Determining a relationship between applied occlusal load and articulation paper mark area. *The Open Dentistry Journal*, *1*(1), 1–7. doi:10.2174/1874210600701010001 PMID:19088874

Daou, E. (2014). The Zirconia Ceramic: Strengths and Weaknesses. *The Open Dentistry Journal*, *8*(1), 33–42. doi:10.2174/1874210601408010033 PMID:24851138

Dawson, P. E. (1995). New definition for relating occlusion to varying conditions of the temporomandibular joint. *The Journal of Prosthetic Dentistry*, *74*(6), 619–627. doi:10.1016/S0022-3913(05)80315-4 PMID:8778387

Dawson, P. E. (1997). A classification system for occlusions that relates maximal intercuspation to the position and condition of the temporomandibular joints. *The Journal of Prosthetic Dentistry*, *75*(1), 60–66. doi:10.1016/S0022-3913(96)90419-9 PMID:8850454

Hämmerle, C. H., Stone, P., Jung, R. E., Kapos, T., & Brodala, N. (2009). Consensus statements and recommended clinical procedures regarding computer-assisted implant dentistry. *International Journal of Oral Maxillofacial Implants.*, *24*, 126–131. PMID:19885440

Kerstein, R. B. (2015). *Handbook of Research on Computerized Occlusal Analysis Technology Applications in Dental Medicine*. Hershey, PA: IGI Global. doi:10.4018/978-1-4666-6587-3

Kerstein, R. B., & Radke, J. (2012). Masseter and temporalis excursive hyperactivity decreased by measured anterior guidance development. *The Journal of Cranio-Mandibular Practice*, *30*(4), 243–254. PMID:23156965

Kerstein, R. B., & Radke, J. (2017). Average Chewing Pattern improvements following disclusion time reduction. *Cranio*, *35*(3), 135–151. doi:10.1080/08869634.2016.1190526 PMID:27332882

Kerstein, R. B., & Wright, N. (1991). An electromyographic and computer analysis of patients suffering from chronic myofascial pain dysfunction syndrome, pre and post - treatment with immediate complete anterior guidance development. *The Journal of Prosthetic Dentistry*, *66*(5), 677–686. doi:10.1016/0022-3913(91)90453-4 PMID:1805009

Kirsch, C., Ender, A., Attin, T., & Mehl, A. (2016). Trueness of four different milling procedures used in dental CAD/CAM systems. *Clinical Oral Investigations*, *21*(2), 551–558. doi:10.100700784-016-1916-y PMID:27469100

Lazzara, R. J., Testori, T., Meltzer, A., Misch, C., Porter, S., del Castillo, R., & Goené, R. J. (2004). Immediate Occlusal Loading (IOL) of dental implants: Predictable results through DIEM guidelines. *Practical Procedures & Aesthetic Dentistry*, *16*(4), 3–15. PMID:15279236

Lorenz, J., Lerner, H., Sader, R.A., & Ghanaati, S. (2017). Investigation of peri-implant tissue conditions and peri-implant tissue stability in implants placed with simultaneous augmentation procedure: a 3-year retrospective follow-up analysis of a newly developed bone level implant system. *International Journal of Implant Dentistry, 3*(41). doi:10.118640729-017-0104-4

McKee, J. R. (1997). Comparing condylar position repeatability for standardized versus non-standardized methods of achieving centric relation. *The Journal of Prosthetic Dentistry*, *77*(3), 280–284. doi:10.1016/S0022-3913(97)70185-9 PMID:9069083

Mettraux, G., Sculean, A., Bürgin, W., & Salvi, G. (2015). Two-year clinical outcomes following non-surgical mechanical therapy of peri-implantitis with adjunctive diode laser application. *Clinical Oral Implants Research*, *27*(7), 845–849. doi:10.1111/clr.12689 PMID:26374080

Misch, C. E. (2008). *Contemporary Implant Dentistry*. St. Louis, MO: Mosby Elsevier.

Prashanti, E., Sumanth, K., & Reddy, J. (2009). Components of Implant Protective Occlusion - A Review. *The Internet Journal of Dental Science*, *7*(2). doi:10.5580/945

Puisys, A., & Linkevicius, T. (2013). The influence of mucosal tissue thickening on crestal bone stability around bone-level implants. A prospective controlled clinical trial. *Clinical Oral Implants Research*, *26*(2), 123–129. doi:10.1111/clr.12301 PMID:24313250

Puisys, A., & Linkevicius, T. (2013). The influence of mucosal tissue thickening on crestal bone stability around bone-level implants. A prospective controlled clinical trial. *Clinical Oral Implants Research*, *26*(2), 123–129. doi:10.1111/clr.12301 PMID:24313250

Qadeer, S., Kerstein, R. B., Yung-Kim, R. J., Huh, J. B., & Shin, S. W. (2012). Relationship between articulation paper mark size and percentage of force measured with computerized occlusal analysis. *The Journal of Advanced Prosthodontics*, *4*(1), 7–12. doi:10.4047/jap.2012.4.1.7 PMID:22439094

Sutter, B. A. (2017). A digital poll of dentists testing the accuracy of paper mark subjective interpretation. *Cranio*, *9*, 18. doi:10.1080/08869634.2017.1362786 PMID:28792294

Tarnow, D. (2009). Clinical Periodontology and Implant Dentistry. Implant Dentistry, 18(2), 101. doi:10.1097/id.0b013e3181a0d4bf

Thoma, D. S., Mühlemann, S., & Jung, R. E. (2014). Critical soft-tissue dimensions with dental implants and treatment concepts. *Periodontology*, *66*(1), 106–118. doi:10.1111/prd.12045 PMID:25123764

Verma, M., Nanda, A., & Sood, A. (2015). Principles of occlusion in implant dentistry. *Journal Of The International Clinical Dental Research Organization*, *7*(3), 27. doi:10.4103/2231-0754.172924

KEY TERMS AND DEFINITIONS

Immediate Loading Protocol: Formulated by Tarnow in 2004, to ensure all implants are rigidly splinted with a metal frame provisional restoration, whereby the patient is allowed to chew only soft foods during the period of osseointegration.

The Key Points in the Digital Workflow Where the T-Scan 10 is Required: To make a preoperative digital occlusal analysis, at the provisional placement to create an optimal provisional occlusal force and timing environment that minimizes movement of the splinted, immediately placed and loaded implants, during prosthesis insertion to finalize the occlusal force and timing profile of the new implant restoration, and at each maintenance recall visits.

Long Term Implant Prosthesis Maintenance: Patients are to recalled every 4 months for control, professional cleaning, re-motivation, and yearly laser induced photodynamic decontamination of the sulcus of the teeth and implants. At each recall, the implant patient should also undergo T-Scan 10 digital occlusal refinement adjustments.

Surgical Placement Guidelines: The accuracy of implant placement and provisional fabrication needed to succeed with digital planning should demonstrate an error of no more than 0.74 mm - 1 mm from the planned surgical entry point, and within 0.85 mm of the planned apex.

Systematic Digital Workflow: A set of occlusally-focused steps to assure a physiologic reproduction of the initial masticatory and muscular system was transferred onto implant rehabilitated tissues, despite changes in the vertical dimension. These steps are the Occlusal and functional diagnosis and registration at the first appointment, the Occlusal adjustment of the provisional and the immediate restoration, the reproduction of the digital contacts in the digital planning procedures of the future reconstruction, the occlusal control of the final restoration at delivery, and the yearly occlusal and functional maintenance of the implant supported reconstruction over the long-term.