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The Desktop Dental Lab

Investigating a new option for chairside milling of custom abutments

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With the recent advent of a compact tabletop precision wet CNC milling machine, dentistry has reached a major milestone in the development of a completely digital workflow for single-tooth implant treatment. This new system brings revolutionary change to in-office dental technology in terms of flexibility, affordability, and control, enabling virtually any dental practice or laboratory the capability of wet milling ceramics, titanium, or polymethyl methacrylate (PMMA).

Combined with a new semi-prefabricated titanium abutment milling blank, the operator can now fabricate equal in quality to an implant manufacturer. These systems complete the loop in providing the clinician or laboratory technician control over the entire dental implant therapy process from surgical planning and surgical guidance to provisionalization and definitive prosthesis fabrication.

The synergy between modern materials and digital technology has yielded increased milling rates and accelerated processing times, facilitating chairside indirect procedures for both conventional and implant prosthodontics. The desktop milling system even makes same-day definitive implant prostheses feasible and practical for any practice or laboratory.

This article introduces the next generation of compact wet milling machines and semi-prefabricated titanium abutment milling blanks and reports on a validation study analyzing the 3-dimensional (3D) accuracy of custom-milled abutments fabricated with these systems. A clinical demonstration of how these transformative innovations enable the implementation of a completely digital workflow concept for dental implant treatment from diagnosis to definitive restoration is illustrated.

A Completely Digital Workflow for Single-Tooth Implants

Three phases are involved in the digital workflow process—acquisition, computer-assisted planning and design, and computer-assisted machining. Research has shown the accuracy of intraoral scanning technologies for acquisition of the tooth preparation and soft tissues,[1] full-arch preparations,[2,3] and single-tooth implants with scan bodies[4] to be at least equal to conventional elastomeric impressions. In a study comparing single-tooth implant digital versus analog impressions, 80% of subjects favored the digital impression, and digital impressions took about half the time of analog impressions.[5]

Radiographic imaging and treatment planning software has revolutionized 3D site assessment, planning of surgical implant placement, and fabrication technologies such as 3D printing or milling of surgical guides. Now by combining cone-beam computed tomography (CBCT) radiography and intraoral scans, the

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FIG. 1

(1.) DentaSwiss DS1300 compact wet 4-axis milling machine and Surface tablet.

provisional crown or custom healing abutment can be milled out in advance from a gradient PMMA material. A recent study compared the physical properties of provisional restorations fabricated from milled PMMA blocks with manually fabricated resin.[6] The researchers concluded that CAD/CAM block restorations had superior color stability, lower water sorption, higher wear resistance, higher surface hardness, and significantly higher fracture resistance. For definitive prostheses fabrication, the shape of the developed soft tissue site and a scan body representing the position of the implant can be scanned intraorally, a virtual model created, and either a hybrid abutment crown or custom abutment and crown designed and milled.

FIG. 2

FIG. 3

(2.) Semi-prefabricated stock titanium milling blank (PreFAB-4 abutment blank). **(3.)** Titanium milled custom abutment validation study specimen.

New Semi-Prefabricated Milling Blank

Titanium alloy has been a popular material of choice for custom abutments due to its compatibility with titanium implants as well as ease and rapidity of milling. While stock abutments allow use of in-office inventory at a lower cost, they can result in restoration cemented margin placement many millimeters below the crest of the gingiva. With the anatomical features of a curved ridge, the greatest potential problem area is at the interproximal zone.

This has potentially deleterious effects on peri-implant tissue health, particularly if the crown must be cemented directly in the mouth. With a 4 to 5 mm subgingival margin, it is virtually impossible to remove the excess cement, risking serious clinical consequences as severe as implant failure.[7-10] Wilson[11] reported that the majority of severe peri-implantitis incidents occurred at 3 years post-restoration cementation. Studies have shown a higher rate of peri-implantitis when using stock abutments versus custom-designed abutments due to the location of the margins with stock abutments.[12]

The control facilitated by a custom-designed abutment with cementation margins just below the crest of the gingiva optimizes long-term peri-implant health and significantly reduces the incidence of soft tissue complications.[12] Ideal margin placement also allows the dentist and hygienist to better evaluate and monitor the implant restoration.

A major concern regarding a custom-milled abutment is the quality of adaptation to the inside of the dental implant. The abutment-implant interface is highly critical to stability of the restoration-abutment-implant complex and long-term peri-implant tissue health.[13] An imperfect fit, especially with an internal conical abutment-implant interface design, can cause abutment screw loosening, restoration mobility, and even implant fracture.[14] Most dental laboratories cannot afford the expensive high-quality, high-accuracy machining equipment of the implant manufacturer necessary for extremely high-precision machining of the critical implant interface portion of the abutment.

A new solution, a semi-prefabricated abutment blank (DentaSwiss PreFAB-4 Concept, Biodenta, www.biodenta.com), was recently 510K cleared and is available for seven implant systems. The critical implant interface portion of the abutment is milled at the factory with high precision (Figure 1) and the coronal portion can then be custom designed and milled by a clinician or a registered dental lab with a lower cost/less sophisticated in-house milling machine. The Ti-6Al-4V alloy abutment blank can be rapidly milled in a wet milling system. This approach has the potential to provide the clinician with more control and flexibility and reduce fabrication costs, but little is known about the accuracy of custom-milled abutments on the latest generation of milling machines.

Compact Wet Milling Machine

The compact, fully automated, self-contained tabletop 4-axis CNC milling machine used in this process has a closed liquid cooling system tank so that no external module for pumping and storage is necessary (DentaSwiss DS1300, Biodenta). The integrated water tank contains a filter mat for separating grinding particles from the cooling liquid. A Surface Pro 3 tablet (Microsoft, www.microsoft.com) with provided DentalCAM software has machining strategies specifically designed for grinding ceramics and other dental materials (Figure 1). Equipped with an automatic tool changer for eight tools, the system has two removable changer stations, a three-ceramic block holder, and two PreFAB-4 blank holders for maximum production capability.

The DentaSwiss DS1300 system is ideal for inlays/onlays, crowns, veneers, three-unit bridges, and patient-specific implant abutments fabricated from PMMA, nano-hybrid composites, glass ceramics, lithium disilicate, silicate ceramics, and titanium. Its size and speed make it well suited for chairside milling operations. Despite its high-speed milling capacity, via the CAM software, it carefully mills occlusal screw access holes atraumatically, avoiding introduction of flaws and cracks in the ceramic structure.

The DentaSwiss system integrates all software and hardware components together and provides full-time technical support necessary to maintain continuous operations. Once the semi-prefabricated titanium milling blank is loaded into the milling machine, along with the design files of the patient-specific coronal and subgingival portion of the abutment, the CAM software calculates the milling paths and the DS1300 wet mills the custom abutment. The desktop milling system offers great flexibility in choice of milling materials, as well as the efficiency, control, and cost-effectiveness of in-house same-day milling rather than outsourcing to a remote milling center. Operators can now have complete control of their digital workflow, tailoring it to their individual systems of dental practice or dental laboratory operations.

Analysis of Milling Accuracy

With all of the promising potential benefits of chairside milling, the accuracy of custom-milled abutments has not been evaluated. The authors set out to determine if the 3D accuracy of custom-milled titanium abutments produced by the system were within acceptable clinical limits.

The ISO developed a standard in 1994 (ISO 5725-1: 1994)[15] for the measurement of accuracy comprising two terms:

- Trueness: The closeness of agreement between the average value obtained from a large series of test results and the accepted test value.
- Precision: The closeness of agreement between independent test results obtained under stipulated conditions.

The purpose of this study was to evaluate the accuracy (trueness and precision) of milled custom abutments fabricated from a semi-prefabricated abutment blank and a new compact 4-axis wet milling machine.[16]

A dental implant (Bone Level Tapered B2 4.1 x 10 mm, Biodenta) was embedded in a dentiform to simulate a single implant placed to restore a missing second premolar with ideal size and proportion. A scan body (DentaSwiss) was placed in the implant and scanned using a dental laboratory scanner (3Shape D2000, www.3shape.com). The scanned image was imported to the dental CAD software (DentaSwiss by 3Shape) and a custom abutment was designed. Ten custom titanium abutments were fabricated from PreFAB-4 abutment blanks (Figure 2) using the DS1300

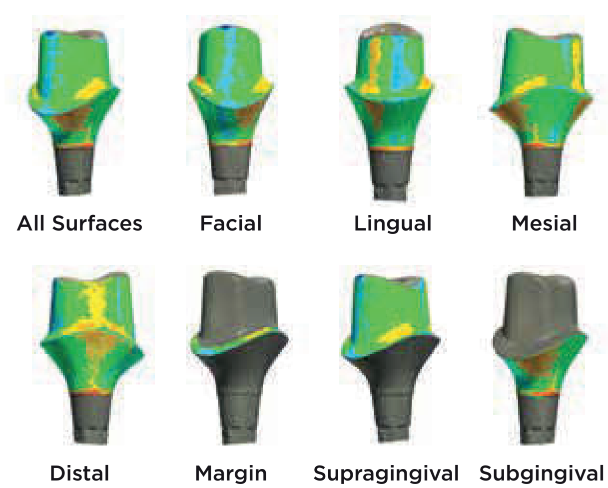

FIG. 4

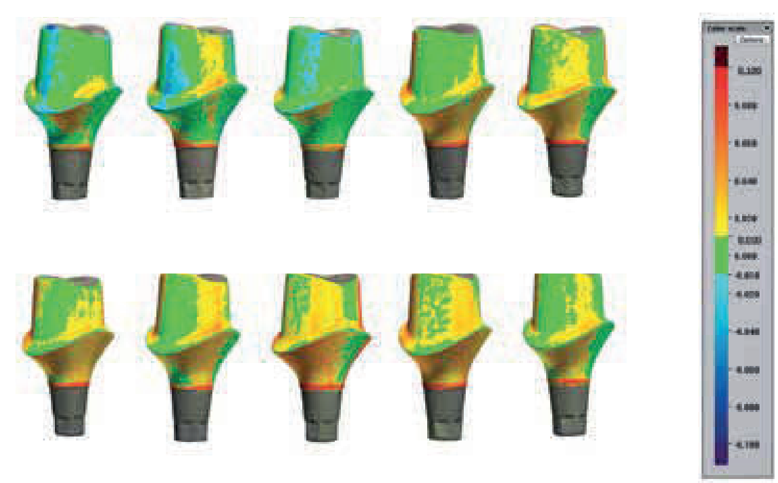

FIG. 5

(4.) Areas of milled abutments that were 3D analyzed for comparison to STL design files. **(5.)** Evaluation of trueness with comparison of the abutment scans to design file.

TABLE 1

Trueness Data with 90% Intervals for all Custom-Milled Abutment Surfaces

Specimen	No. of Points	Min.	Max.	Mean	Standard Deviation	90% Interval	90% Interval Lower Limit	90% Interval Upper Limit	RMS
1	6123	-85.8	55.1	0.4	14.8	0.4±24.3	-23.9	24.7	14.8
2	6064	-211.1	61.4	1.7	18.3	1.7±30.1	-28.4	31.8	18.4
3	6483	-85.4	52.3	0.1	12.8	0.1±21.1	-21.0	21.2	12.8
4	5628	-50.9	74.1	12.4	15.6	12.4±25.7	-13.3	38.1	19.9
5	5997	-126.3	72.4	14.5	15.4	14.5±25.3	-10.8	39.8	21.2
6	5836	-104	65	15.8	14.2	15.8±23.4	-7.6	39.2	21.3
7	5863	-121.3	63.3	12.9	13.5	12.9±22.2	-9.3	35.1	18.7
8	5901	-37.1	79.5	19.9	15.2	19.9±25.0	-5.1	44.9	25.1
9	6007	-90.7	78.4	17.3	14.8	17.3±24.3	-7.0	41.6	22.7
10	6094	-93.6	60.6	9.6	14	9.6±23.0	-13.4	32.6	16.9
Avg	5999.6	-100.62	66.21	10.46	14.86	10.5±24.4	-13.98	34.9	19.18

RMS = Root mean square. All units in µm.

(Figure 3). The occlusal surface sprue was manually cut and polished. Specimens were scanned using the same D2000 scanner and scanned images imported to the software (3Shape Convince Analyzer) for comparison.

First, scanned images were superimposed over the original design to evaluate trueness. Superimposed images were analyzed for discrepancy between two images. Overall analysis was performed; then each area (facial, lingual, mesial, distal, margin, supragingival, subgingival) was analyzed separately (Figure 4). Various statistics were calculated and one-way ANOVA repeated measurement and Bonferroni tests were used to compare root mean square displacement (RMSD) of each area. To evaluate precision, comparisons between each specimen were made and statistical analyses were performed in the same way.

For trueness, the average 90% interval of overall errors was 10.5±24.4 µm (Figure 5). The 90% intervals for various areas are listed in Table 1. One-way ANOVA repeated measurement and Bonferroni tests showed that the RMSD of subgingival area was greater than the other areas.

For precision, the average 90% interval of overall errors was 7.8±17.7 µm and 90% intervals for various surfaces listed in Table 2. One-way ANOVA repeated measurement showed that there was no statistically significant difference in RMSD between surfaces.

In summary, the average 90% interval overall errors for trueness was 10.5±24.4 µm and for precision was 7.8±17.7 µm. Within the limitations of this study, the PreFAB4 titanium blank that was tested using DentaSwiss 3Shape and the DS1300 milling system was fabricated with a high degree of accuracy that is equal to or exceeds conventional fabrication methods.

With the high precision of the milled custom abutments, laboratory fabrication procedures can be simplified and made more efficient by milling the zirconia or lithium disilicate ceramic crowns simultaneously.

Clinical Demonstration of Completely Digital Workflow

A patient presented with a carious non-restorable endodontically treated root No. 4 (Figure 6). After clinical examination, an intraoral


FIG. 6

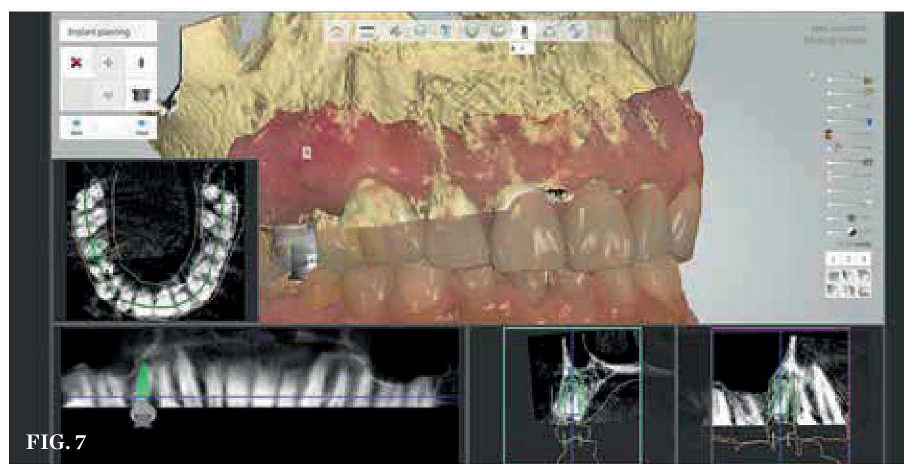
FIG. 7

(6.) Preoperative view of non-restorable root tooth No. 4. **(7.)** 3Shape Implant Studio software combining CBCT and intraoral scan to plan surgical implant placement.

TABLE 2

Precision Data with Average 90% Intervals of Overall Errors for Various Surfaces

Surface	No. of Points	Min.	Max.	Mean	Standard Deviation	90% Interval	90% Interval		RMS
							Lower Limit	Upper Limit	
All	5819.2	-43.5	74.0	7.8	10.8	7.8±17.7	-9.9	25.5	15.9
Facial	3088.0	-29.8	54.5	7.6	10.6	7.6±17.4	-9.8	24.9	15.4
Lingual	2790	-40.8	52.3	8.0	10.0	8.0±16.5	-8.5	24.5	15.8
Mesial	3019.8	-27.5	56.8	7.8	10.2	7.8±16.7	-8.9	24.5	15.4
Distal	2950	-47.2	59.4	7.8	10.5	7.8±17.2	-9.4	25.0	15.8
Margin	1027	-21.6	39.8	8.6	10.5	8.6±17.3	-8.7	26.0	15.1
Supragingival	3769	-43.6	67.1	7.8	10.8	7.8±17.7	-9.9	25.6	15.3
Subgingival	2372	-18.8	43.6	8.5	9.6	8.5±15.8	-7.3	24.4	16.4

RMS = Root mean square. All units in µm.

scan (TRIOS® Color, 3Shape) was performed. A CBCT radiograph was made of the maxillary arch and DICOM files imported into Implant Studio (3Shape). The design software was used to perform a 3D evaluation of available bone and plan surgical implant placement (Figure 7).

The radiographs showed a mesial bone defect and distally tilted root. To maintain at least 1.5 mm of bone between the distal of tooth No. 5 and bone at the anterior sinus wall, a 4.1x10 mm tapered implant (Biodenta, Bone Level B2) was selected.

With angulated root sockets, a common challenge during the initial osteotomy is that the twist drill wants to follow the path of least resistance. The surgical guide can ensure correct vertical implant placement. A tooth-supported surgical guide was designed and milled out of clear PMMA disk in a 5-axis milling machine (DentaSwiss DS2000).

With the predictability of surgically guided implant placement, a hybrid PMMA provisional crown was designed and milled out in advance of the surgery in the DS1300.

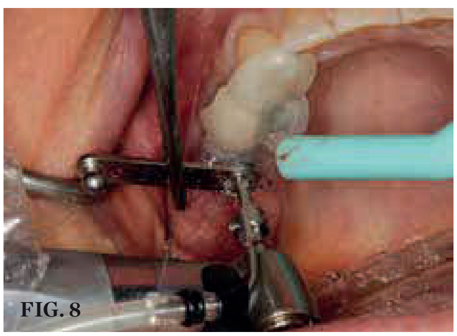
FIG. 8

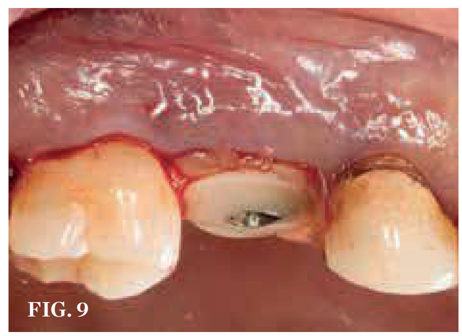
FIG. 9


FIG. 10

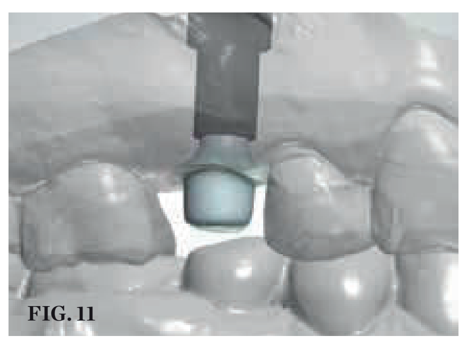
FIG. 11


FIG. 12


FIG. 13


FIG. 14

(8.) Milled surgical guide used for precise osteotomy and implant positioning. **(9.)** Milled custom healing abutment and grafting material in place. **(10.)** Postoperative radiograph demonstrating excellent implant positioning. **(11.)** Custom abutment CAD screen capture. **(12.)** Simultaneously milled custom titanium abutment and lithium disilicate crown. **(13.)** Postoperative radiograph of tooth No. 4. **(14.)** Postoperative view of monolithic zirconia crown on custom titanium abutment of tooth No. 4.

The root was atraumatically elevated with periotomes and the socket palpated with a periodontal probe confirming that the buccal wall was intact. The surgical guide was seated, the irrigated 2-mm twist drill aligned with the metal insert, and precisely seated to depth (Figure 8). The predetermined series of surgical drills was followed using the guide.

Because the insertion torque was only 15 Ncm, it was elected to cut off the clinical crown of the pre-surgically milled hybrid provisional crown and convert it to a custom healing abutment for soft tissue site development (Figure 9). The custom healing abutment also secured the grafting material and membrane. An intraoperative radiograph revealed sound implant positioning with ideal bone dimensions interproximally (Figure 10).

For definitive restoration fabrication, a scan body was placed and an intraoral scan performed. A virtual model was created and several definitive restoration scenarios pursued. A custom abutment and crown were designed (Figure 11) and abutment milled from a PreFAB-4 blank in the DS1300. A monolithic zirconia crown (NexxZr®T, Sagemax, www.sagemax-dental.com) was milled and differentially shaded to an A3.5 shade. A lithium disilicate (IPS e.max®, Ivoclar Vivadent, www.ivoclarvivadent.com) crown was also milled simultaneously with the custom titanium abutment in the DS1300 system (Figure 12).

On delivery, the custom abutment was seated and ceramic crowns tried in; proximal contacts and occlusion were checked. The crowns were polished with either the Dialite® ZR or Dialite® LD system (Brasseler USA, www.brasselerusa.com). The zirconia crown was selected and cemented with SpeedCEM (Ivoclar Vivadent) on the custom abutment in the laboratory. The retrievable abutment crown was seated on the implant, the abutment screw torqued to the appropriate level, and screw access hole filled with PTFE tape and composite resin (Figure 13 and Figure 14).

Summary

All of the components necessary for a completely digital workflow have finally come together. The transformative technology of a compact desktop wet milling machine combined with the semi-prefabricated titanium milling blank enable the dental clinic or dental lab to perform same-day milling of an implant abutment, ceramic crown, or hybrid ceramic crown. Intraoral scanning devices, design software developments, and integration of all the components in the process bring dentistry to a new age in digital implant prosthodontics. Equally encouraging is that these technologies are highly affordable and give the practice or lab the freedom and control to produce cost-effective custom abutments yet still deliver high precision without compromise.

Disclosure

John A. Sorensen, DMD, PhD, FACP and Hongseok An, DDS, MSD, have no relevant financial interests to disclose.

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