THE CUTTING EDGE

(Editor's Note: This quarterly column is compiled by JCO Technology Editor Ronald Redmond. To help keep our readers on The Cutting Edge, Dr. Redmond will spotlight a particular area of orthodontic technology every three months. Your suggestions for future subjects or authors are welcome.)

This month's Cutting Edge column proposes an innovative approach to occlusal splint fabrication. The authors, Dr. Stephen P. Warunek and Mr. Mark Lauren, show how TMD splints can be made using technology from CAD/CAM processes that were originally designed to produce inlays, crowns, and partial denture frameworks.

I am impressed by the .001" precision of the occlusal splint fabrication described in the article. This degree of accuracy should greatly enhance the use and delivery of occlusal splints for TMJ treatment. In addition, taking the human component out of the equation should eliminate the variability of traditional splint fabrication.

Progress in three-dimensional CAD/CAM processing appears to be accelerating—even the source of the 3D data is changing as I write this introduction. The authors use a photographic system, the Minolta VIVID, to collect their 3D data, but cone-beam scans may soon replace this method, offering the ability to collect most of our traditional diagnostic records at the same time.

CAD/CAM will not only aid in the production of highly accurate appliances, but will be able to predict possible treatment outcomes. Technological advances continue to allow orthodontists to develop and hone our most important skills: diagnosis and treatment planning.

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Computer-Based Fabrication of Occlusal Splints for Treatment of Bruxism and TMD

Computer-aided design/computer-aided manufacturing (CAD/CAM) technology was first used in dentistry in 1985 for in-office fabrication of ceramic inlays.[1] Known as CEREC,* short for "computer-assisted ceramic reconstruction", this process and other laboratory-based systems can now be used to produce a variety of single- and multiple-unit ceramic restorations.[2-4] Similar methods have been described for construction of milled titanium implant abutments[5,6] and removable partial denture frameworks.[7] In orthodontics, the Invisalign** system uses stereolithography to convert computer-based tooth setups into solid models for fabrication of series of thermoformed plastic aligners.[8] CAD/CAM techniques have also been used to produce occlusal splints for orthognathic surgery,[9] customized orthodontic archwires,[10] and bracket-archwire combinations.[11]

The 2005 JCO Orthodontic Practice Study reported that about 25% of American orthodontists offer TMJ treatment to their patients.[12] Current evidence suggests that occlusal splints can reduce (but not eliminate) bruxism, protect teeth from stress and attrition, and diminish pain associated with masticatory myalgia or TMJ arthralgia.[13-17] Before and after orthodontic treatment with fixed appliances, full-coverage, flat-plane stabilizing splints are generally worn at night and for one to two hours during the day. Sullivan described an

*Sirona Dental Systems, LLC, 4835 Sirona Drive, Charlotte, NC 28273; www.sirona.com.

**Registered trademark of Align Technology, Inc., 881 Martin Ave., Santa Clara, CA 95050; www.aligntech.com.

occlusal splint that attaches directly to fixed appliances during orthodontic treatment.[18]

Because a variety of manual articulation and trimming methods are used to fabricate these splints, there are differences among laboratories and even among technicians working in the same laboratory. More important, the final contact surface is the result of the technician's subjective determination of smoothness, meaning that no two splints will be identical, even if made by the same technician for the same patient. To address these shortcomings, Great Lakes Orthodontic Laboratories introduced Digital Splint Fabrication*** in 2007. This article describes how the system uses computer-based design to produce splints for the treatment of bruxism and TMD.

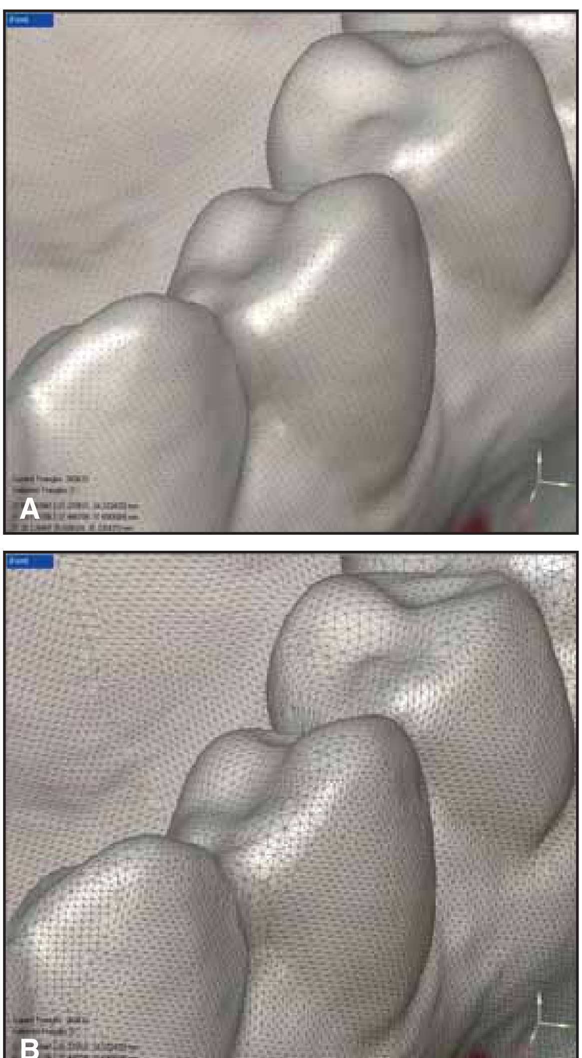

Fig. 1 Laser scan. A. Point cloud data. B. Polygonal model.

Model Scanning

Stone casts attached to standard mounting plates are laser-scanned using a Minolta VIVID camera system.† Six individual scans taken 60° apart are combined into a single object. The scanner collects data as ordered points (Fig. 1A), and the software converts them into a polygonal three-dimensional model (Fig. 1B). The scanning system is calibrated to index the casts to the mounting plates. For unmounted casts, a 3D digital bite record is created from a combination scan, which incorporates single facial laser scans of the maxillary and mandibular casts with the provided centric relation (CR) bite registration in place.

Articulation

Mounted casts are positioned on the computer screen exactly as on a laboratory articulator, using the mounting plates as a reference. Condylar inclination angle, eminence curves, and Bennett angle are individually controlled. These variables allow protrusive and lateral excursions to be built into the splint design.

For unmounted casts, the mandibular arch is used to determine a hinge axis. In the standard articulation method, the mandibular occlusal plane is oriented at a 15° angle to horizontal, and the hinge axis is located at a 100mm axis-incisal distance and 50mm vertical height. These parameters can be individually controlled. The digital system also allows the use of patient-specific values obtained from direct clinical measurements. With the hinge axis determined, the maxillary arch is then posi-

***Trademark of Great Lakes Orthodontics, Ltd., 200 Cooper Ave., Tonawanda, NY 14151; www.greatlakesortho.com.

†Konica Minolta Sensing Americas, Inc., 101 Williams Drive, Ramsey, NJ 07446; www.konicaminolta.us.

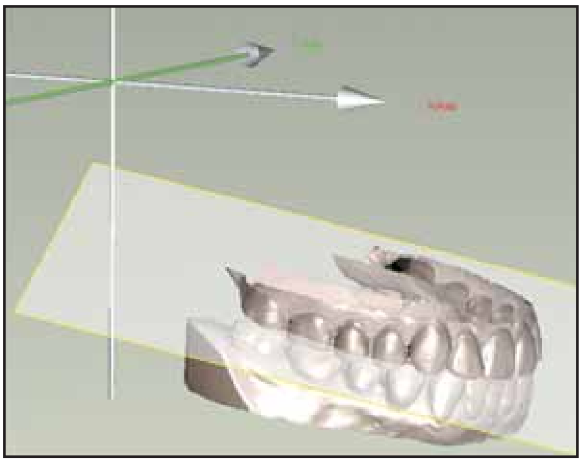

Fig. 2 Scanned models positioned in relation to hinge axis.

tioned using the combination scan (Fig. 2). Software control is similar to that for mounted casts.

Design

Splint design requires the determination of several parameters, including the occlusal opening, contact points, shelf width, ramp positions, and perimeter or shape of the splint. The cast receiving the splint is termed the splint cast, and the opposing arch is called the contact cast.

First, the opening is adjusted to the desired setting. A chairside CR bite registration close to the desired opening should be obtained for maximum accuracy.

Contact points are then determined by clicking on the surface of the contact cast image. Since the contact point cannot be precisely positioned, the software relocates it to the ideal site. In a case with a relatively normal curve of Spee, the chosen point is relocated to the point on the tooth closest to the occlusal plane of the contact cast. With a large curve of Spee, the contact points can be optimized based on the arc of closure, which involves repositioning the initial point to the first location on the tooth that is cut by a plane rotated about the centric axis. The optimization feature can be turned off to select a contact point manually.

After each contact point is determined, a sur-

Fig. 3 Contact points, surface normals, and perpendicular circular "islands" defined on mandibular arch.

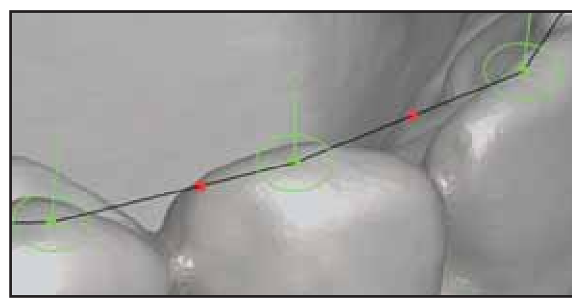

Fig. 4 Markers for incisor and canine guidance ramps (red squares).

face normal is computed, and a perpendicular circular "island" is constructed (Fig. 3). A best-fit plane is passed through the islands to form a contact plane, which is the flattest possible surface connecting all the contact points. A horseshoe-shaped portion of this plane, incorporating the contact points and covering the teeth of the opposing arch, becomes the functional surface of the splint.

To fabricate a flat-plane splint, the width of the surface anterior and posterior to the contacts must be specified. This is important in cases with large overjets to ensure that the protrusive shelf is long enough. Splints may also be designed with incisor and canine ramps that provide posterior disclusion when the patient moves the jaw anteriorly or laterally. The extent of the incisor and canine ramps is determined by placing four markers on the line connecting the contact points (Fig. 4). The incisor ramp is built between the two mesial markers, and the canine ramp between the two distal

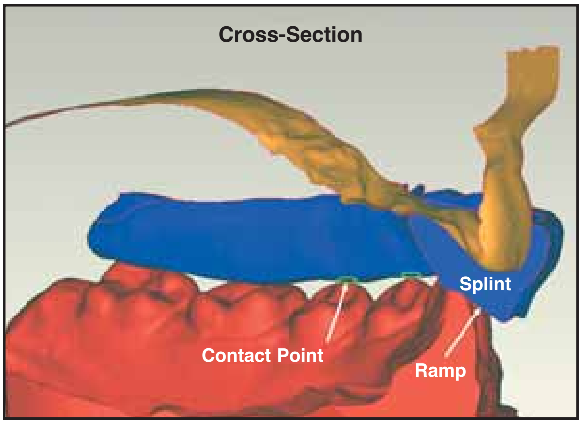

Fig. 5 Sagittal midline cross-section of virtual models and splint with anterior ramp.

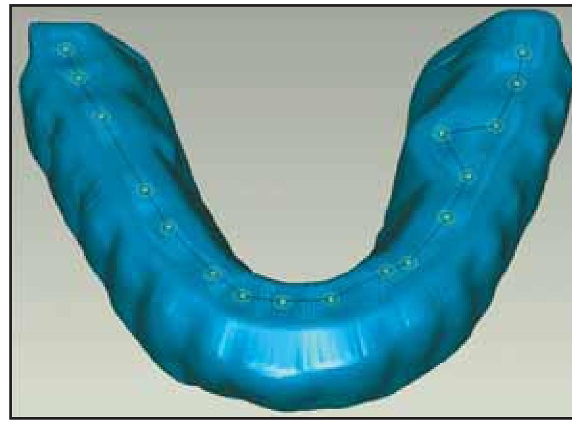

Fig. 6 Contact points between maxillary flat-plane splint and mandibular arch outlined with green circles in final stage of computer design.

markers. The length and angle of each ramp can be independently controlled. The ramp angle required to provide no disclusion is first computed, and the ramp is then angled 5° past this theoretical angle to provide mild disclusion. Splints with ramps are often prescribed for patients with significant overbites to prevent excessive bite opening (Fig. 5).

The final design step is to determine the perimeter and overall shape of the splint by clicking a series of points on the image of the splint cast. The contact points between a maxillary flat-plane splint and the mandibular arch are outlined with green circles on the screen (Fig. 6).

Production

The designed splint is saved as a 3D surface file, which is directly imported into CAM software.†† The splint cast is covered with the desired material and mounted in a Haas vertical machining center.‡ The splint is then produced by machining the excess material down to the final splint surface (Fig. 7). Sequentially smaller tools are used, with the largest tool possible always selected to achieve maximum smoothness (Fig. 8).

Fig. 7 Acrylic splint mounted in vertical machining center to remove excess material.

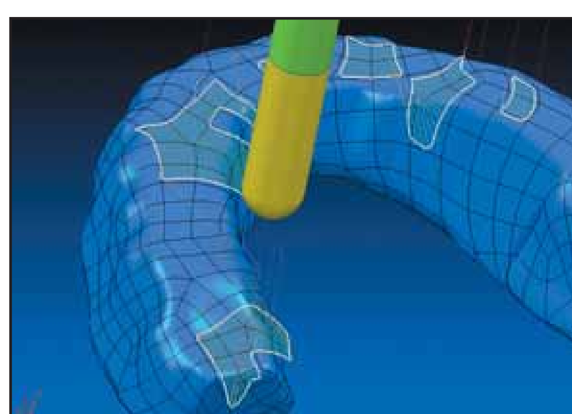

Fig. 8 Computer image showing areas identified with white outlines for finer machining.

††PowerMILL, Delcam PLC, 275 E. South Temple, Suite 305, Salt Lake City, UT 84111; www.powermill.com.

‡Haas Automation Inc., 2800 Sturgis Road, Oxnard, CA 93030; www.haascnc.com.

Fig. 9 Cast fabricated with block-out material over fixed attachments.

Because the functional contact surface is machined to an accuracy of less than .001", it does not require further finishing.

Discussion

Computer-based fabrication of flat-plane occlusal splints has several advantages over conventional manual production methods, including greater consistency among laboratories and individual technicians, better quality control during the manufacturing process, and faster production. In addition, digitally fabricated splints have smooth, divot-free occluding surfaces that allow freer mandibular movement and provide better symptom relief than with conventional splints.

Although hard acrylics have traditionally been used to make occlusal splints, soft materials can also be used. In a double-blind study involving 23 patients with TMD, Pettengill and colleagues found no differences between hard and soft splints in the reduction of masticatory muscle pain.[19] Materials suitable for soft digital splint fabrication include ethylene vinyl acetate (EVA, typically used for mouthguards and some tooth positioners), hard-soft laminates, and heat-softening acrylics. In our experience, adults with cosmetic bonding and crowns prefer soft EVA material when given a choice. No signs of occlusal wear or deformation have been observed after several months of night-time wear, although long-term durability remains to be assessed.

Soft splints are also suitable for patients undergoing orthodontic treatment, in whom conventional splints are difficult to use because of interference with fixed appliances and restriction of tooth movement. A soft flat-plane digital splint may be fabricated from a cast made with appropriate block-out material over the fixed attachments (Fig. 9).

In our experience with digitally produced facebow-mounted and unmounted splints of all material types, none required more than 15 minutes of chairside adjustment time, with some needing no alterations. In total, 3,000 splints have been manufactured using this method; anecdotal reports suggest an overall reduction in chairside delivery time. Current research is investigating methods of incorporating patient-specific parameters into splint articulation and design. CAD technology is also being used to enhance the design of splints for patients in active orthodontic treatment.

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REFERENCES

1. Mörmann, W.H.: The evolution of the CEREC system, J. Am. Dent. Assoc. 137(Suppl.):7S-13S, 2006.
2. Otto, T. and De Nisco, S.: Computer-aided direct ceramic restorations: A 10-year prospective clinical study of Cerec CAD/CAM inlays and onlays, Int. J. Prosthod. 15:122-128, 2002.
3. Fasbinder, D.J.: Clinical performance of chairside CAD/CAM restorations, J. Am. Dent. Assoc. 137(Suppl.):22S-31S, 2006.
4. Calabro, K.: CAD/CAM outsourcing: How to maximize the lab-to-lab partnership, Lab Mgt. Today 23:10-14, 2007.
5. Priest, G.: Virtual-designed and computer-milled implant abutments, J. Oral Maxillofac. Surg. 63(9 Suppl. 2):22-32, 2005.
6. Drago, C.J.: Two new clinical/laboratory protocols for CAD/CAM implant restorations, J. Am. Dent. Assoc. 137:794-800, 2006.
7. Williams, R.J.; Bibb, R.; Eggbeer, D.; and Collis, J.: Use of CAD/CAM technology to fabricate a removable partial denture framework, J. Prosth. Dent. 96:96-99, 2006.
8. Wong, B.H.: Invisalign A to Z, Am. J. Orthod. 121:540-541, 2002.
9. Okumura, H.; Chen, L.H.; Yokoe, Y.; Tsutsumi, S.; and Oka, M.: CAD/CAM fabrication of occlusal splints for orthognathic surgery, J. Clin. Orthod. 33:231-235, 1999.
10. Sachdeva, R.: Sure-Smile: Technology-driven solution for orthodontics, Tex. Dent. J. 119:608-615, 2002.
11. Mujagic, M.; Fauquet, C.; Galletti, C.; Palot, C.; Weichmann, D.; and Mah, J.: Digital design and manufacturing of the Lingualcare bracket system, J. Clin. Orthod. 39:375-382, 2005.
12. Keim, R.G.; Gottlieb, E.L.; Nelson, A.H.; and Vogels, D.S. III: 2005 JCO Orthodontic Practice Study, Part 2: Practice success, J. Clin. Orthod. 39:687-695, 2005.
13. Kreiner, M.; Betancor, E.; and Clark, G.T.: Occlusal stabilization appliances: Evidence of their efficacy, J. Am. Dent. Assoc. 132:770-777, 2001.
14. Türp, J.C.; Komine, F.; and Hugger, A.: Efficacy of stabilization splints for the management of patients with masticatory muscle pain: A qualitative systematic review, Clin. Oral Investig. 8:179-195, 2004.
15. Sheikholeslam, A.; Holmgren, K.; and Riise, C.: A clinical and electromyographic study of the long-term effects of an occlusal splint on the temporal and masseter muscles in patients with functional disorders and nocturnal bruxism, J. Oral Rehab. 13:137-145, 1986.
16. Chung, S.C.; Kim, Y.K.; and Kim, H.S.: Prevalence and patterns of nocturnal bruxofacets on stabilization splints in temporomandibular disorder patients, Cranio 18:92-97, 2000.
17. Korioth, T.W.; Bohlig, K.G.; and Anderson, G.C.: Digital assessment of occlusal wear patterns on occlusal stabilization splints: A pilot study, J. Prosth. Dent. 80:209-213, 1998.
18. Sullivan, T.C.: A new occlusal splint for treating bruxism and TMD during orthodontic therapy, J. Clin. Orthod. 35:142-144, 2001.
19. Pettengill, C.A.; Growney, M.R. Jr.; Schoff, R.; and Kenworthy, C.R.: A pilot study comparing the efficacy of hard and soft stabilizing appliances in treating patients with temporomandibular disorders, J. Prosth. Dent. 79:165-168, 1998.