Current Opinion in DENTISTRY

Reviews of all advances · Evaluation of key references
Comprehensive listing of papers

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CURRENT SCIENCE

lation, and electromyographic biofeedback. *J Prosthet Dent* 1990, 63:472–477.

5. LUND JP, WIDMER CG: **An evaluation of the use of surface ••** **electromyography in the diagnosis, documentation, and treatment of dental patients.** *J Craniomandib Disord Facial Oral Pain* 1989, 3:125–137.

Extensive review of the literature regarding the clinical use of EMG activity.

6. LASKIN DM, GREENE CS: **Technological methods in the diagnosis and treatment of temporomandibular disorders.** *Int J Technol Assess Health Care* 1991, in press.

7. LASKIN DM, GREENE CS: **Diagnostic methods for temporo- ••** **mandibular disorders: what we have learned in two decades.** *Anesth Prog* 1990, 37:66–71.

Reviews studies on devices that measure aspects of jaw and muscle function, imaging, diagnostic appliances, and diagnostic arthroscopy. The authors conclude that the only diagnostic techniques that currently have proved to be valid are hard-tissue radiographs, soft-tissue imaging, and arthroscopy for direct examination of the temporomandibular joint.

8. TALLEY RL, MURPHY GJ, SMITH SD, BAYLIN MA, HADEN JL: **Standards for the history, examination, diagnosis, and treatment of temporomandibular disorders (TMD): a position paper.** *J Craniomandib Pract* 1990, 8:60–77.

9. DOUGLASS CW, MCNEIL BJ: **Clinical decision analysis methods applied to diagnostic tests in dentistry.** *J Dent Educ* 1983, 47:708–712.

10. HELKIMO M: **Studies on function and dysfunction of the masticatory system.** *Swed Dent J* 1974, 67:101–121.

11. NIELSEN, IL, MARCEL T, CHUN D, MILLER AJ: **Patterns of •** **mandibular movements in subjects with craniomandibular disorders.** *J Prosthet Dent* 1990, 63:202–217.

The authors used jaw tracking to determine if movement patterns in craniomandibular disorder patients were different than in controls. Calibrations were used, and reproducibility was tested. Problems with the design include use of multiple *t*-tests for statistical analysis and a repeated measure design on a subset of patients without repeating the evaluation on controls (to determine normal variation).

12. OZAKI Y, SHIGEMATSU T, TAKAHASHI S: **Analysis of the chewing movement in temporomandibular disorders.** *Bull Tokyo Dent Coll* 1990, 31:91–103.

13. FEINE JS, HUTCHINS MO, LUND JP: **An evaluation of the criteria used to diagnose mandibular dysfunction with the mandibular kinesiograph.** *J Prosthet Dent* 1988, 60:374–380.

14. KARLSSON S, CARLSSON GE: **Characteristics of mandibular masticatory movement in young and elderly dentate subjects.** *J Dent Res* 1990, 69:473–476.

15. TALLGREN A, MIZUTANI H, TRYDE G: **A 2-year kinesiographic study of mandibular movement patterns in denture wearers.** *J Prosthet Dent* 1989, 62:594–600.

16. SIDELSKY H, CLAYTON JA: **A clinical study of joint sounds in subjects with restored occlusions.** *J Prosthet Dent* 1990, 63:580–586.

17. BRUDVIK JS, HOWELL PGT: **Evaluation of eccentric occlusal contacts in complete dentures.** *Int J Prosth* 1990, 3:146–157.

18. MUNAKATA Y, KASAI S: **Determination of occlusal vertical dimension by means of controlled pressure against tissues supporting a complete denture.** *J Oral Rehabil* 1990, 17:145–150.

19. GOULET J-P, CLARK GT: **Clinical TMJ examination methods. ••** *J Calif Dent Assoc* 1990, 18:25–33.

Measured reliability for certain aspects of the clinical examination. The authors showed good reliability in jaw movement (using a millimeter ruler), joint palpation, and muscle palpation. These techniques are reliable and can be useful in TMD diagnosis.

20. KATZ JO, RUGH JD, HATCH JP, LANGLAIS RP, TEREZHALMY GT, • BORCHERDING SH: **Effect of experimental stress on masseter and temporalis activity in human subjects with temporomandibular disorders.** *Arch Oral Biol* 1989, 34:393–398.

Showed a possible lack of habituation to stress by EMG measurement. Good controls were used (matched for age and gender). Even with a biased sample of patients (biased toward having a relationship between stress and TMD), the absolute EMG value differences were small.

21. NIELSEN IL, MCNEILL C, DANZIG W, GOLDMAN S, LEVY J, MILLER • AJ: **Adaptation of craniofacial muscles in subjects with craniomandibular disorders.** *Am J Orthod Dentofacial Orthop* 1990, 97:20–34.

Showed a difference in muscle activity during function in certain masticatory muscles in patients with craniomandibular disorders. The jaw-tracking instrumentation was calibrated, and the EMG-activity assessment was blinded. In analyzing the data, a multivariate analysis of variance would be more appropriate than the multiple one-way analysis of variance tests used in the study.

22. DAHLSTROM L, HARALDSON T: **Immediate electromyographic •** **response in masseter and temporal muscles to bite plates and stabilization splints.** *Scand J Dent Res* 1989, 97:533–538.

Found no statistical differences in EMG activity using splints with the same vertical dimension of occlusion, although the authors did note some "trends" in the findings. However, it should be remembered that "trends" in research results should be regarded as finding no difference between groups. When values are not statistically different, there is an unacceptable level of the phenomenon occurring by chance.

23. SHI CS: **Proportionality of mean voltage of masseter muscle to maximum bite force applied for diagnosing temporomandibular joint disturbance syndrome.** *J Prosthet Dent* 1989, 62:682–684.

24. HOLMGREN K, SHEIKHOLESLAM A, RIISE C, KOPP S: **The effects of an occlusal splint on the electromyographic activities of the temporal and masseter muscles during maximal clenching in patients with a habit of nocturnal bruxism and signs and symptoms of craniomandibular disorders.** *J Oral Rehabil* 1990, 17:447–459.

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CAD/CAM imaging in dentistry

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CAD/CAM (computer-assisted design/computer assisted manufacturing), although devised 20 years ago, has only been available for routine dental practice for 2 years. As a supplement to the conventional methods for making dental prostheses, CAD/CAM will have profound effects on the dental profession. CAD/CAM will improve versatility, accuracy, and cost effectiveness and will be a part of routine dental practice by the beginning of the 21st century.

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A dental prosthesis is designed to reconstruct, partially or totally, the portions of the oral-facial complex using manufactured products. For over 200 years, the fabrication process has undergone constant evolution leading to progressively more excellent results, but requiring rather awkward operations. Traditional methods, such as making the impression, pouring the cast, waxing, and casting, remain rather fundamental. Dental CAD/CAM (computer-assisted design/computer-assisted manufacturing) offers an extraordinary opportunity to introduce into dentistry the most modern techniques from physical science and mathematics. Although devised 20 years ago, CAD/CAM has only been available for routine dental practice for 2 years. A review of the evolution of dental CAD/CAM will indicate how this new technology has grown and demonstrate some of its capabilities. Although CAD/CAM currently has daily application, the first results indicate substantial future development that will have a profound effect on the dental profession.

Description of CAD/CAM

Dental CAD/CAM is the application of computer-assisted design and manufacture to dentistry. To this has been added a first step of capturing information, analogous to making an impression. CAD/CAM systems are technically complex instruments whose operation involves three distinct steps: gathering information, designing the restoration, and fabricating the restoration.

The first step: collection of information

The first step, which for a long time has been the specialty of dental CAD/CAM, is the collection of the maximum amount of intraoral information in association with certain diagnostic and therapeutic elements. This guarantees correct software function and the creation of an individualized prosthesis.

After preparation of the area to be treated, the dentist makes the optical reading or measurement using an electromechanical or electrooptical capture device, either directly in the mouth, or indirectly on a cast. Most CAD/CAM methods use the metrological properties of the laser beam for measuring, and those of the charged coupled device camera for reading. Even though some methods substitute the use of a micropalpation device for the camera, or use a second charged coupled device instead of the laser, these systems remain quite similar for the most part. The laser or "structured" lights [1] can be represented by the projection of a fine fringe or one of several screens whose superimposition allows one to obtain particular physical phenomena, such as Moire, and assures three-dimensional recognition of the object. Irrespective of the method of imaging, this measurement leads to the three-dimensional capture of a cloud or pattern of points representative of the object and referenced in space. This does not differ much from the traditional method, in which the stone cast serves as a storage of information, and does not require any prior knowledge of the relative position of each point that constitutes the surface. The second part of this first step consists of indicating on the digitized object and reconstructing on the video screen a certain number of points and information whose specific identification is crucial to the fabrication of the prosthesis (contact areas, physical boundaries, identification of occlusal determinants, and others). This operation, conducted by the practitioner, will be followed by calculation of the surface topography and correlation of multiple views if more than one image has been made.

Abbreviations

CAD—computer-assisted design; **CAM**—computer-assisted manufacturing.

The second step: design of the prosthesis

The second step is the creation step derived from classical industrial CAD, but whose software uses concepts unique to dentistry. One of its most important fundamental properties is that a functionally and artistically satisfactory restoration will be created from the oral impression and some additional information with no prior knowledge of any forms or volumes. The process is far more advanced in this area than methods of x-ray scanning or imaging using magnetic resonance, wherein an object is only visualized, but cannot be produced. This ability requires a creative and evolving expert system capable of responding to all of the situations that might be encountered. This also requires a very professional interactive instrument. One may return at any time to the preceding interactive step during the process of modeling and constructing both the internal surface (allowing consideration of needed cement space) and the external surface (providing development of the desired occlusal morphology) of the prosthesis. Only one of the systems presented here has this capability, and it remains reserved for the most sophisticated. Some systems merely reproduce the negative of the preparation, requiring a manual finishing of the unknown external surfaces. Only the systems completely modeling all surfaces and creating them truly merit the name *dental CAD/CAM*.

The third step: manufacture of the prosthesis

The third [2•] and final step corresponds to the manufacturing of the prosthesis created during the preceding steps. This is usually a classic milling procedure using various degrees of technological sophistication ranging from a simple pantographic device that copies a manually created model to the true four-axis milling center with automatic tool changing. In all instances, dental CAD/CAM is completed using traditional manual finishing procedures.

Various systems for creating dental prostheses using a computer

At this writing, there are two commercially available systems that can be called *dental CAD/CAM*. Perhaps some are about to be presented for distribution, but some information is contradictory, and discretion is advised. Systems will be discussed in ascending order of complexity.

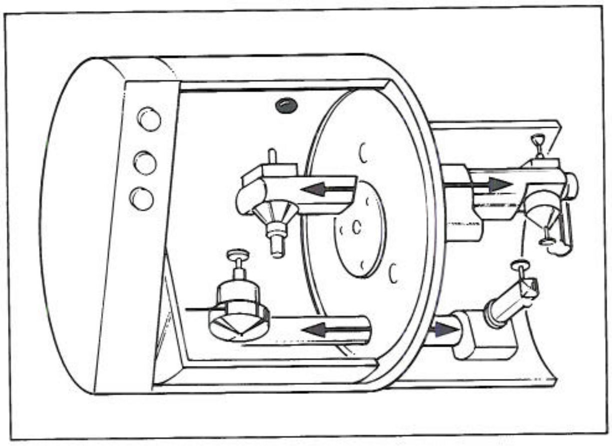

Fig. 1. Sketch of the CELAY system. Tracing of the pattern on the left side of the unit provides information for the machining of the ceramic restoration.

The CELAY system

The CELAY system [3•] (Mikrona Technologie, Spreitenbach, Switzerland) is a micropalpation system and uses a four-axis micromilling device. It is used only for inlays and onlays. The dentist must first develop the desired restoration using hard resin that can resist deformation while being read by the palpation tracing device. This resin restoration is placed under the tip of a tracing device (Fig. 1) whose form is exactly like that of the milling tool. The material for the finished restoration is placed under the machining head. These reading and milling units are linked by a pantographic arm. The cutting tool follows the profile indicated by the reading head that traces the resin model. This method allows the creation of an inlay, including the occlusal surface, in approximately 20 minutes without having to use a casting technique or an optical impression. However, it requires the fabrication of an intermediary unit in the mouth or on a cast, a time-consuming and delicate procedure. The method is limited insofar as the type of prosthesis that can be created, and is relatively expensive.

The Procera system

The first publications on the Procera (Nobelpharma Inc., Göteborg, Sweden) system date from 1987 [4 ••]. It is a simple copying and milling system using a pantograph and electroerosion system. The system is designed for the fabrication of titanium copings through the following process: a die of the preparation is made using classic impression-and-cast procedures. The die must be hard enough to resist abrasion by the pantographic tracing point. The die is placed under a reading point connected to a milling system by a pantographic arm. A carbon graphite duplicate die is made that is uniformly slightly dilated to provide space for cement. Usually, three carbon dies are created in this manner. The original die is also used to guide the milling of titanium, using greater uniform expansion adequate to allow the desired thickness of metal in the finished coping. This creates a titanium coping shaped as an expanded form of the original preparation. The internal surface of this piece of titanium is then formed using an electroerosion process. The titanium piece is placed upside down on an electroerosion plate, while the carbon die, acting as the milling electrode, is progressively inserted into the internal part. Inasmuch as some of the integrity of the carbon die is lost during the process, one or more new rods are used to refine the machining. Following the electromilling process, the titanium coping is veneered with resin or porcelain.

This system has been the object of a clinical study and shows interesting results. A number of patients have been treated in Sweden using crowns produced by the this method [5•], and acceptable results have been reported. The cost has not yet been announced. The process takes approximately 1 hour and is limited to the production of a coping. The advantage is that the coping is fabricated from titanium, a very biocompatible material.

The Titan system

The Titan system [6•] is a composite procedure that has not yet been completed. It involves reading by micropalpation tracing, a CAD station, and a CAD milling unit. This device is produced by the Swiss firm, DCS Dental in Allschwil, and should be introduced in 1993. Even though the information available is still contradictory, it appears that the manipulation principle is as follows; The tooth preparation is made in the conventional manner. Information is gathered either directly from the tooth or from a die, using the micropalpation tracing device in either instance. This information is transferred to a CAD computer. The CAD system is not yet fully developed but appears to resemble that of the Duret system. The milling of a titanium form is accomplished from data issued by the software, using a professional-type machine tool and numerical commands. This system is still in the preproduction stage, so it is impossible to provide any information on the quality of the restorations created. The system allows the creation of titanium restorations and has an announced cost of between $300,000 and $350,000.

The Cerec system

The Cerec system uses data that is gained from an optical method taken either from a stone die or directly intraorally. The Cerec system was developed by an engineer (Marco Brandestini) and a dentist (Werner Mörmann) of Zurich, Switzerland [7]. This system is manufactured by the Siemens Dental Corp. (Benshein, Germany). The first professional publication dates from 1985, and approximately 250 systems have been sold throughout the world. There are several scientific studies done by various university teams [8•] that give a precise idea of the characteristics of this device.

The Cerec equipment is a compact assembly [9 ••] enclosing an image-treatment station with screen, and a micromachine tool using two and one half axes. A camera using a 256 X 256 charged coupled device allows the capture of information about the inlay or onlay preparation. Only one view can be made. The absence of the CAD stage means that the machine tool can only mill the interior of the inlay or the laminate veneers. The external or occlusal portion must be created manually in the mouth or on the die. This restoration is created using Dicor glass-ceramic (Dentsply International, York, PA) or Vita porcelain material (Vita Zahnfabrik, Bad Sachingen, Germany).

Although the method is limited in its applications, its precision of marginal adaptation is within approximately 100 μ [10•]. At $35,000, it is cost effective. Its compactness, simplicity, and maneuverability make it practical to use. Approximately 45 minutes are necessary to complete an inlay.

The Duret system

The Duret system is the result of 20 years of research and development by Duret [11•,12] and his team of engineers. It is the first known CAD/CAM system. It is in use in 30 dental offices in France and at an American Dental School (USC) [13 ••].

This system unites the three basic components of dental CAD/CAM: optical reading, CAD, and milling (Fig. 2). The optical impression is made from a cast or directly in the mouth by a 512 × 512 charged couple device camera using an interferometric method derived from electronic Moire patterns. It allows the taking of a view and the correlation of up to 16 different images. The CAD station allows the creation of all the classic prosthodontic elements: coping, crown, inlay, and soon, fixed partial dentures, including the external and occlusal surfaces. In particular, the connection of this device with an electronic articulator (Access Articulator, under contract development) assures an incorporation of the kinematic mandibular movements into the design of the occlusal surfaces. The milling, in metal, ceramic, composite resin, or organo-ceramic (Aristee, Spad, Dijon, France) materials is accomplished using a 3.5-axis machine tool custom designed for this application. The fabrication of a crown requires approximately 1 hour [14]. The system remains in limited distribution with a price that is quite expensive ($200,000). However, the variety of restorations possible, along with a precision of less than 50 μ at the marginal junction, leads one to believe that it will remain the spearhead of the new technology. Its effectiveness in routine dental practice remains to be seen.

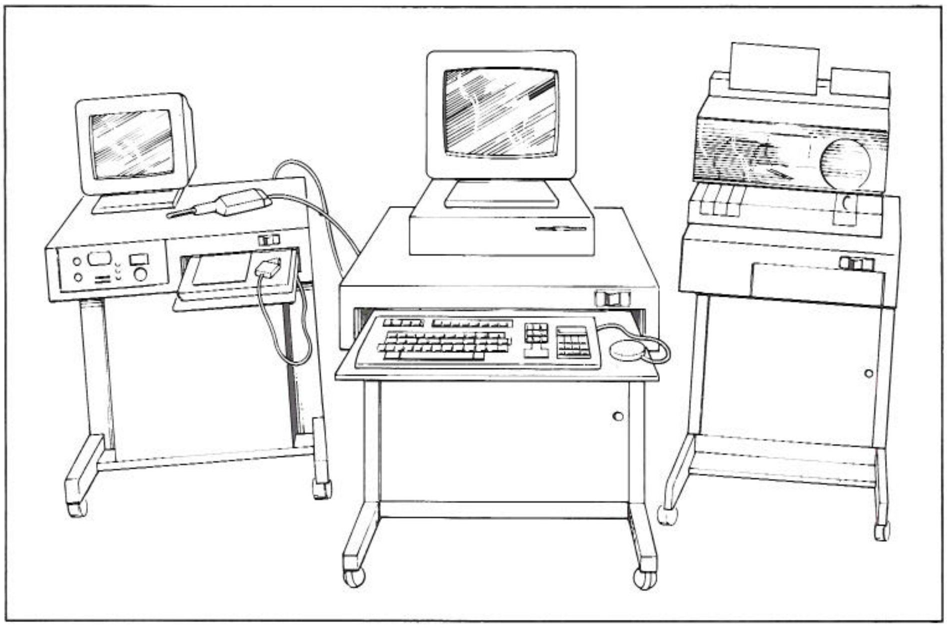

Fig. 2. Sketch of the Hennson system showing the imaging station (*left*) with laser camera, mouse, and display monitor. The CAD station (*center*) is primarily mouse-driven and has a high-resolution monitor. The CAM unit (*right*) is a small, self-contained complete machining system.

Systems under development

A number of systems are being developed, but have yet to be publicly displayed, and it is difficult to know their actual level of advancement. Their developers are respected and dedicated in their work. The two systems most well known and apparently technically close are those of Rekow (Baltimore, Maryland) [15•,7] and Tsutsumi (Kyoto, Japan).

The Rekow DentiCAD system

Rekow (unpublished data, 1991), is developing a system that she has stated will produce crowns, inlays, and eventually, fixed partial dentures. Now working at the University of Maryland in Baltimore, Rekow recently moved from intraoral photogrammetry and laboratory laser imaging to a form of micropalpation. A tracing probe resembling a periodontal probe relays intraoral information on the form of the tooth preparation that is used with the CAD system to create the desired form. The milling machine is intended to work with resin, ceramic, or metal materials. Single crowns fabricated from a laboratory cast using the previous CAD/CAM system design have been presented by Rekow. This system was recently licensed to BEGO GmbH (Bremen, Germany).

The Kyoto Project

Tsutsumi of Kyoto University heads a team of scientists working to produce a CAD/CAM system based on optical recording [16•]. The system uses the projection of a light structured by a laser fringe and stereoscopic recording. The level of the CAD system is not known. A conventional CAM unit operated using numerical commands is used.

Until these systems are actually in use and the costs and relative accuracy are known, any other statements would be conjecture.

Conclusions

While the first dental CAD/CAM machine was presented in 1983 and the first crown created in 1985, 4 more years were required before the first systems were built and used in dental offices. It is the opinion of the authors that the systems will continue to improve in versatility, accuracy, and cost effectiveness, and that they will be a part of routine dental practice by the beginning of the 21st century.

Annotated references and recommended reading

Papers of special interest, published within the annual period of review, have been highlighted as:
- • Of interest
- •• Of outstanding interest

1. BIEMANN A: **Three-dimensional machine vision.** *Photonics Spectra* 1988, 22:81–92.
2. • DUNCAN J, LAW K: *Computer-Aided Sculpture.* Cambridge ed. Cambridge University Press, 1989, pp 162.

An excellent book on the modeling and milling of awkward forms, written by one of the pioneers of CAD/CAM.

3. • *CELAY System Catalog* Mikrona Technologie, Spreitenbach, Switzerland, 1990, pp 1–4.

The only known document on the CELAY system (Mikrona Technologie Spreitenbach, Switzerland).

4. •• ANDERRSON M, BERGMAN B, BESSING C, ERICSON E, LUNDQUIST P, NILSON H: **Clinical results with titanium crowns fabricated using duplication and spark erosion.** *Acta Odontol Scand* 1989, 47:279–286.

Description of the method with very good figures. Presents the first clinical results.

5. BERMAN B, BESSING C, ERICSON G, LUNDQUIST P, NILSON H,
• ANDERSSON M: **A follow-up study of titanium crowns.** *Acta Odontol Scand* 1990, 48:113–117.

The authors present clinical results of the Procera (Nobelpharma Inc, Göteburg, Sweden) system and provide a very in-depth study.

6. *Unser DCS Titan System Catalog*: DCS Dental 1990,
• pp 2.

The only known document on the Titan (DCS Dental, Allschwil, Switzerland) system.

7. WILLIAMS AG: **The Switzerland and Minnesota developments in CAD/CAM.** *J Dent Pract Adm* 1987 4:50–54.

8. HEYMANN HO: **CAD/CAM: exploring the Cerec system.** *Den-*
• *tistry Today* 1990, 9:6–54.

The author presents results of the use of the Cerec system in the United States. However, some errors are noted.

9. MÖRMANN WH, BRANDESTINI M: *Die CEREC Computer Recon-*
•• *struction: Inlays, Onlays, and Veneers*. Quintessenz Verlags-GmbH 1989, pp 250.

An excellent work that must be read. It offers a complete description of the Cerec system (Siemens Dental Corp. Benshein, Germany).

10. MOERMANN WH, BRANDESTINI M: **Chairside computer-aided**
• **direct ceramic inlays.** *Quintessence Int* 1989, 20:329–339.

The authors give their opinion of Cerec (Siemens Dental Corp., Benshein, Germany) and present the clinical results. It is a good classification of FDA standards.

11. CATANEO P: **Special informatique.** *Dent Hebdo* 1991,
• 197:13.

The author gives a resume of the use of a computer in a dental office and offers an opinion on the Hennson system in France.

12. WILLIAMS AG: **Dentistry and CAD/CAM, another French revolution.** *J Dent Pract Adm* 1987, 4:2–5.

13. CROOKS C: **CAD/CAM comes to USC.** *USC Dentistry* 1990,
•• Spring:14–17.

A good description of Hennson's CAD/CAM as seen by University of Southern California.

14. DURET F, BLOUIN JL, DURET B: **CAD/CAM in dentistry.** *J Am Dent Assoc* 1988, 117:715–720.

15. REKOW D: **Computer-aided design and manufacturing in den-**
• **tistry: a review of the state of the art.** *J Prosthet Dent* 1989, 58:512–516.

An older paper, but it is one of the basic articles on CAD/CAM.

16. KIMURA H, SOHMURA T, WATANABE T: **Three-dimensional**
• **shape measurement of teeth. Part 3: on the measurement by the newly developed laser displacement meter with double sensors.** *J Osaka Uni Dent* 1990, 2:295–300.

One of the numerous articles written by this team. It is a good description of reading by laser fringe.

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