Clinical results with titanium crowns fabricated with machine duplication and spark erosion

Matts Andersson, Bo Bergman, Christer Bessing, Gunnel Ericson, Peter Lundquist and Hans Nilson

Public Dental Health Service, County of Jämtland, and the Department of Prosthetic Dentistry, Faculty of Odontology, University of Umeå, Umeå, Sweden

Andersson M, Bergman B, Bessing C, Ericson G, Lundquist P, Nilson H. Clinical results with titanium crowns fabricated with machine duplication and spark erosion. Acta Odontol Scand 1989;47:279–286. Oslo. ISSN 0001-6357.

A new method for fabrication of metal crowns has been developed by one of the authors (M.A.). There are two principles involved: machine duplication of models and electric discharge machining. The metal used is pure unalloyed titanium, which is processed as a coping and later covered by a composite resin. In 1986, 205 separate titanium crowns were made on 149 patients. One year later 192 crowns on 137 patients could be examined. Five crowns had been replaced by new ones owing to fracture of the composite resin. In accordance with the CDA quality evaluation system the following results were obtained for the remaining 187 crowns: margin integrity, 186 excellent or satisfactory (99.5%); anatomic form, 185 excellent or satisfactory (98.9%); and surface and color, 181 excellent or satisfactory results (96.8%). The 1-year results are promising, and further follow-up studies will be made. □ *Clinical behavior; dental materials; fixed restorations*

Bo Bergman, Faculty of Odontology, University of Umeå, S-90187 Umeå, Sweden

Since the beginning of this century casting by means of the lost-wax technique has been the dominant method when fabricating metal crowns in dentistry. In the field of industrial manufacturing various methods have been developed to increase precision when working with metals. One of these methods is spark erosion, which was introduced in industry more than 30 years ago. Spark erosion has been applied in dentistry for fabrication of attachments and other components of removable prostheses (1, 2) and for inlays, crowns, and bridges (3–6). However, the spark erosion method as used in the above-cited papers utilizes some technical procedures that preserve certain error sources associated with conventional methods and introduce others. Andersson & Andersson (7) have developed a method by which the principles of spark erosion are combined with a method of machine duplication. With these combined techniques several error sources associated with the casting technique when fabricating metal crowns have been eliminated. When introducing a new method for fabrication of crowns, it is necessary to perform an adequate clinical evaluation of the restorations. The aim of the present paper is to describe the new combined technique for fabricating titanium crowns and report on a 1-year longitudinal study of treatment with such crowns.

Materials and methods

Crown fabrication

Titanium is exceptionally well tolerated in biologic environments, where it has a high corrosion resistance (8). Pure titanium is a cheap metal and has been used for a long time in dental implants—for example, in the successful long-term treatment with the Brånemark implants (9). For the present purpose it was decided to try to use the same quality of titanium for crowns as used for dental implants—that is, A TI 24 and A TI 30 (Avesta, Sweden). However, titanium is not easily precision cast, so its use has been

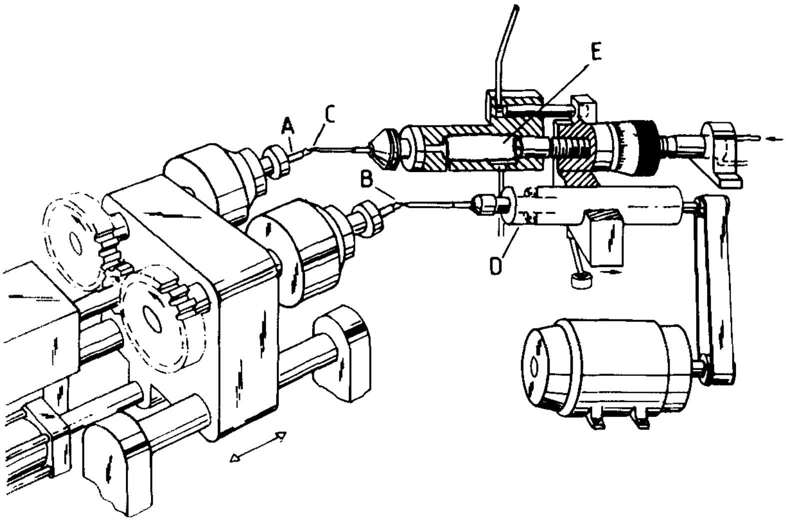

Fig. 1. The coping milling machine with (A) the holder for the stone die, (B) the blank to be produced as a copy of A with the help of the detection needle (C). D is the milling device, and E the hydraulic servo unit.

limited mainly to wrought, rolled, or otherwise fabricated applicances.

Thus with regard to the difficulties in casting titanium, two other methods were applied—machine duplication and spark erosion. In this way a coping was shaped out of a solid piece of titanium. The coping was thereafter veneered with a composite resin. The total process involves a) a tool system that enables the model of the tooth—a stone die—to be repositioned with great precision; b) a coping milling machine, on which the shape of the model can be reproduced with great precision; and c) a spark erosion process with short processing time and low electrode wear (carbon electrode). The tool system will make it possible to copy the position of the tool in the other machines, and the machining of the inner and the outer contour can be made quite independent of each other.

The principal design of the coping milling machine is shown in Fig. 1. There are two co-rotating elements that hold the stone replica, A, and the blank, B, which is to be machined to become a copy of A. The replica and the blank are mounted on guides enabling simultaneous longitudinal displacement along their axes of rotation. A detection needle, C, interacts with the surface of the replica during its rotation and longitudinal displacement. The movements of the detection needle are transmitted to the milling device, D, by a hydraulic servo, E. This transmission enables a simultaneous processing of the blank, B, to a copy of the replica A.

The accuracy of the servo unit is related to the velocity of the servo, which again depends on the surveying speed and on how complex the form of the item is. When sur-

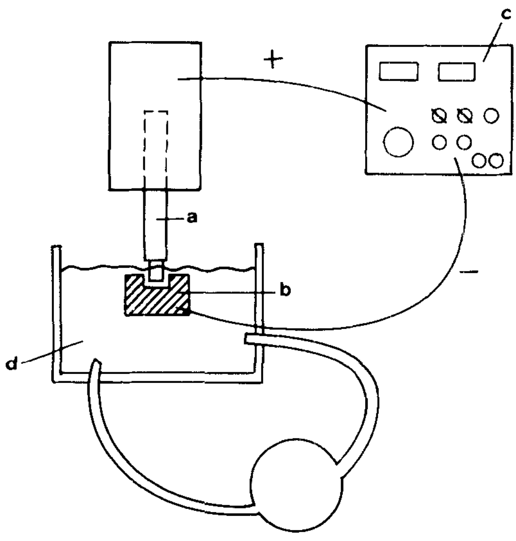

Fig. 2. The electrical discharge machine with (a) the workhead, (b) the table, (c) the generator, and (d) the work tank.

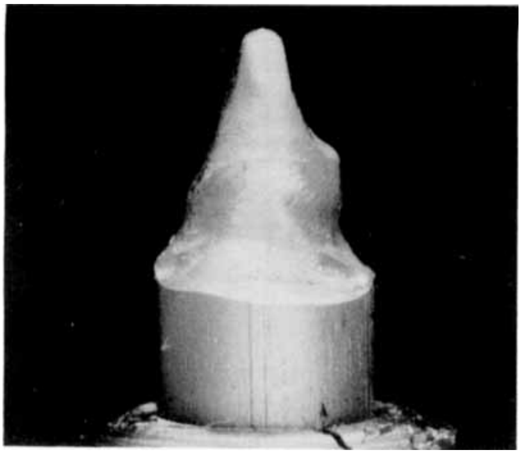

Fig. 3. The titanium copy of the stone die.

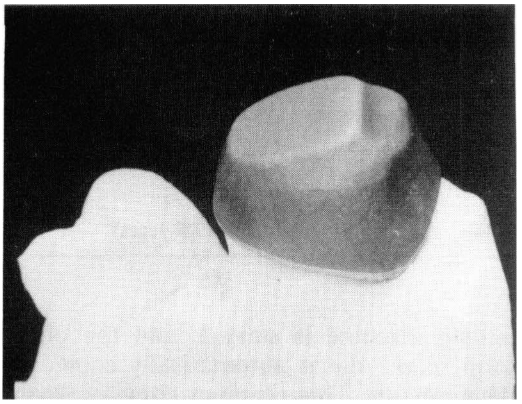

Fig. 5. The titanium coping with its rough surface before the application of the veneering material.

veying, the servo speed should not exceed 5–10% of the maximum servo speed. That gives a surveying time of about 2 min per preparation. When the shape of the stone die is very complex, the surveying speed has to be slowed down to ensure a precise fit.

The die sinking electrical discharge machining (EDM) apparatus has the following principal design (Fig. 2): a) a workhead, which consists of a spindle that is run by a servo, either electric or hydroelectric; b) a table, often a two-coordinate one, where the workpiece can be positioned; c) a generator, which delivers the sparks. Together with the generator there is also a control unit monitoring the movement of the workhead; and d) a work tank in which the process takes place under protection of a dielectric fluid. The control unit ensures that there is always a constant gap between electrode and workpiece. In coordination with the removal of metal from the workpiece, the electrode is progressed forward.

The procedure is in brief as follows. The stone die is placed in a tool. Thereafter the stone is positioned in a profile projector and suitable dimensions of titanium blank and carbon electrode are chosen. In the milling procedure the tools with stone die and titanium blank are placed in a spindle, the

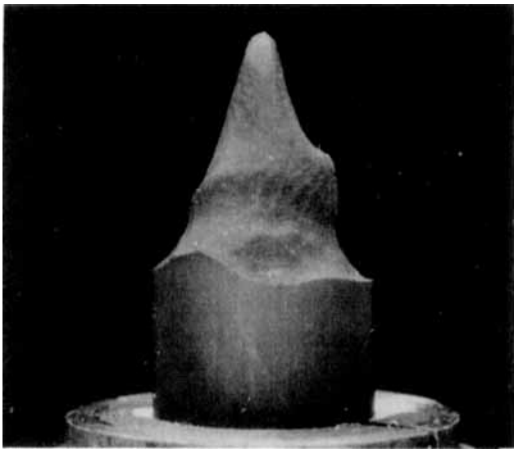

Fig. 4. The carbon blank of the stone die.

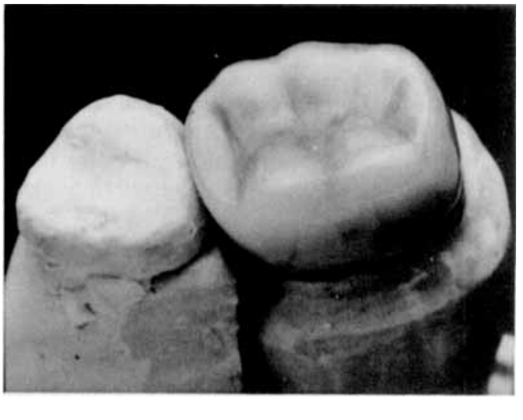

Fig. 6. The completed titanium crown covered with the veneering material Dentacolor®.

Table 1. Number of patients treated with titanium crowns and examined in 1986 (= zero) and re-examined in 1987 (= 1 year)

	No. of patients examined	
	Zero	1 year
Male	67	57
Female	82	80
Total	149 (mean age, 47.5 years)	137 (mean age, 48.9 years)

milling machine is started, and the outer form of the die is automatically copied in the titanium. This titanium copy is evenly enlarged, so that the milled surface represents the outer surface of a future cap with adequate wall thickness (Fig. 3). The stone die is transferred to a machine equipped for carbon milling. The carbon blank is mounted, and the carbon electrode is milled to a copy of the stone die. This carbon copy can also be enlarged to give any desirable compensation for the cement layer between the tooth and the titanium coping (Fig. 4).

After being detached the milled titanium blank is mounted in another tool, which is placed in the table of the EDM apparatus. The milled carbon electrode is placed in the spindle of the same machine. The EDM apparatus is started, and the inner cavity of the coping is processed automatically. There is a certain wear of the electrode, so that two or three electrodes are usually needed for each coping to give the accurate shape of the cavity. The total time for the spark erosion process is 8–10 min per coping. When the EDM processing is finished, the coping is checked and thereafter polished on surfaces not to be veenered, using the same methods and materials as for polishing gold castings. Surfaces to be veneered are left rough, to facilitate mechanical retention for the veneering material (Fig. 5). For veneering, two composites have been used. The first 90% of the crowns in the present series were veneered with Isosit®, which is a heat-cured resin bonded mechanically to the rough titanium surface. The remaining 10% were veneered with the light-cured resin Dentacolor®, using the Silicoater® technique to achieve a bond between titanium and the composite resin (Fig. 6).

Clinical study

In the spring of 1986, 205 separate titanium crowns were made in 149 patients. The design of the clinical study had been approved by the Swedish National Board of Health and Welfare and the Ethical Review Committee of the Medical Faculty at the University of Umeå. The treatment was performed by 27 general practitioners in the Public Dental Health Service in the four northernmost counties in Sweden. The patients were volunteers selected among ordinary recall patients in need of crown therapy. They were treated with conventional clinical methods. The same principles as for preparation of teeth for metal–ceramic crowns were followed. Titanium crowns were made on both vital and root-filled teeth. If root-filled, the tooth was provided with a cast post and core in a type 3 gold alloy. After the crowns had been cemented—time zero—they were examined by four licensed specialists in prosthetic dentistry who had undergone calibration with regard to the evaluation methods used (10). The following three characteristics were evaluated in accordance with 'Quality Evaluation for Dental Care' issued by California Dental Association (11): surface and color, anatomic form, and margin integrity. Further-

Table 2. The distribution of crowns examined in 1986 and (in parentheses) in 1987

	Maxilla	Mandible	Total
Incisors and canines	60 (57)	16 (16)	76 (73)
Premolars	64 (55)	32 (30)	96 (85)
Molars	14 (12)	19 (17)	33 (29)
Total	138 (124)	67 (63)	205 (187)

Table 3. Judgement of the characteristic 'surface and color' in accordance with the CDA system for the 187 titanium crowns that could be examined both in 1986 (= zero) and in 1987 (= 1 year)

	Zero		1 year	
Satisfactory				
Excellent	156 (83.4%)	98.4%	131 (70.1%)	96.8%
Acceptable	28		50	
Not acceptable				
Replace or correct	3	1.6%	—	3.2%
Replace statim	—		6*	

* Five fractures of the Isosit + one crown with large porosities in the Isosit.

more, Bleeding Index (12) and Margin Index (13) were registered. When judging Bleeding Index, a contralateral tooth or a tooth as close as possible to the contralateral one was chosen as control.

Each crown was examined by any two of the four calibrated specialists independently of each other. Whenever disagreements in rating of a given crown occurred, the two examiners resolved their disagreement by joint examination.

After 1 year, in 1987, the patients were recalled. Of the original 149, 137 could be examined (Table 1). The reasons of the 12 for not attending were as follows: 3, abroad; 3, moved away from the region; 2, ill; 2, deceased; 1, on vacation; and 1, reason unknown.

The re-examined 137 patients had been provided with 192 titanium crowns. However, from the initial examination to the 1-year control, five of these crowns had been replaced owing to extensive fractures of the veneering material, the composite Isosit. The comparisons between zero and 1-year figures are therefore limited to 187 crowns. Of the 187 control teeth 94 were provided with some type of full crown, 87 with fillings, and 6 were intact.

The distribution of titanium crowns made and examined in 1986 and examined in 1987 is shown in Table 2.

Table 4. Judgement of the characteristic 'anatomic form' in accordance with the CDA system for the 187 titanium crowns that could be examined both in 1986 (= zero) and in 1987 (= 1 year)

	Zero		1 year	
Satisfactory				
Excellent	118 (63.1%)	100%	113 (60.4%)	98.9%
Acceptable	69		72	
Not acceptable				
Replace or correct	—		2*	1.1%
Replace statim	—		—	

* Two insufficient occlusal contacts owing to wear.

Table 5. Judgement of the characteristic 'margin integrity' in accordance with the CDA system for the 187 titanium crowns which could be examined both in 1986 (= zero) and in 1987 (= 1 year)

	Zero		1 year	
Satisfactory				
Excellent	166 (88.8%)	100%	161 (86.1%)	99.5%
Acceptable	21		25	
Not acceptable				
Replace or correct	—		—	0.5%
Replace statim	—		1*	

* Caries.

Table 6. Bleeding Index in percentage judged in accordance with Lenox & Kopczyk (12) for the 187 teeth with titanium crowns (T) and the control teeth (C) which could be examined both in 1986 (= zero) and in 1987 (= 1 year)

	Mesial		Buccal		Distal		Lingual	
	T	C	T	C	T	C	T	C
Zero	28.3	27.8	11.2	10.2	31.0	32.6	13.9	16.0
1 year	21.9	18.2	23.5	16.6	28.3	31.6	32.6	27.3

Results

CDA ratings

During the follow-up period five crowns had been replaced owing to fractures of the composite resin, thereby reducing the number of crowns to be examined at 1 year to 187. Of these, six crowns were judged not acceptable at the 1-year examination, five because of fractures of the composite (Table 3). Thus the number of fractured veneers during the 1st year amounts to 10 out of 192 (5.2%). The ratings presented refer to 187 crowns.

When the factor surface and color was rated as satisfactory (excellent or acceptable), there was a small decrease between zero and 1 year from 98.4% to 96.8% (Table 3). However, when comparing the rating excellent only, there was an obvious decrease from 83.4% to 70.1%. With regard to anatomic form (Table 4) and margin integrity (Table 5), there were only minor changes between the initial and 1-year ratings, no matter how the comparisons were made.

Bleeding Index

There was a decrease in bleeding approximally and an increase buccally and lingually with regard to teeth provided with titanium crowns (Table 6). The same tendency was found for the control teeth. Comparable bleeding rates were very similar when teeth with titanium crowns were compared with the control teeth.

Margin Index

The initial rating showed that the margins of the titanium crowns approximally to a greater extent were located at or below the gingival margin compared with the buccal and lingual surfaces (Table 7). After 1 year the subgingivally located margins had increased in number approximally, as had both the supragingivally and subgingivally located margins buccally and lingually. The latter observations are in accordance with a substantial decrease of the number of crown margins rated as degree 2 (= level with the gingival margin) at the 1-year control.

Table 7. Number of surfaces with Margin Index judged in accordance with Silness (13) for the 187 titanium crowns that could be examined both in 1986 (= zero) and in 1987 (= 1 year)

Margin Index*	Mesial		Buccal		Distal		Lingual	
	Zero	1 year	Zero	1 year	Zero	1 year	Zero	1 year
0	0	0	4	7	0	0	3	3
1	2	2	13	22	2	5	30	42
2	45	19	107	76	38	20	115	89
3	140	166	63	87	147	162	39	53

* 0 = Restoration margin more than 2 mm above the gingival margin; 1 = restoration margin less than 2 mm above the gingival margin; 2 = restoration margin level with the gingival margin; and 3 = restoration margin below the gingival margin.

Discussion

In the present study spark erosion has been combined with a method of machine duplication for fabrication of crowns. With this combined technique the inherent error sources from waxing, investment, and casting procedures are eliminated. These error sources are associated with conventional methods for fabrication of metal crowns and partly also with previous attempts to adapt spark erosion for this purpose (3–6). The present method enables high precision and accuracy because of the possibility of modifying the electrode in relation to the stone die. In this manner both the spark erosion time and the final dimension can be affected. According to preliminary tests (Øilo 1986, personal communication) the resulting gap between the die and the coping is in a range comparable with that of well-made cast conventional gold alloy copings. It also seems reasonable to assume that the fact that the copings are fabricated from one solid piece of titanium, an exceptionally biocompatible metal, without the heat treatments included in conventional casting procedures will create conditions for keeping corrosion at a very low level.

Of the initial 149 patients 137, or 92%, could be examined after 1 year. The reasons for the non-attendance of 12 patients do not indicate any association with factors pertaining to the study. Therefore, there is every reason to believe that the results after 1 year would have been the same if it had been possible to examine all patients.

It can be concluded that the 1-year results with the present 187 titanium crowns are promising. The margin integrity of the crowns had a high rating at both zero and the 1-year control. The veneering material used in the first 90% of the cases was the composite Isosit. During the present 1-year control period this material disclosed some shortcomings, as there were veneer fractures in 10 crowns, of which 5 had been replaced at the 1-year control. This may be due to insufficient reduction of tooth substance especially occlusally/incisally. Furthermore, several changes from excellent to acceptable were noted with regard to surface and color. The observations of fractures and surface and color changes indicate that other veneering materials may be more compatible with titanium copings. The last 19 crowns in the present series were veneered with the composite Dentacolor, using the Silicoater technique. The registered observations with Dentacolor in the present study have not as yet shown any of the above-mentioned disadvantages. The shift to a new veneering material took place during late spring of 1986. Since then a large number of titanium copings veneered with the Dentacolor/Silicoater method have been cemented in patients. A clinical study of this material is in progress (B. Bergman, H. Nilson, M. Andersson. Unpublished observations).

It has recently been reported that the light-cured resin Dentacolor showed a markedly lower substance loss than the heat-cured resin used (14). Although the long-term wear of Dentacolor and of Isosit as veneer materials for titanium copings is a matter of future research, it can be noted that the findings of the present study do not contradict those of Ekfeldt & Øilo (14).

A 1-year observation period with this new type of titanium crown is short. To enable more detailed, long-term comparisons with other clinical studies on various types of crowns the present patient material will be followed up continuously.

Acknowledgement.—This study has been financially supported by the Board for Technical Development (STU), Stockholm, the Development Fund of the County of Jämtland, the Investment Company of the County of Jämtland, the Counties of Jämtland, Norrbotten, Västerbotten and Västernorrland, and the University of Umeå. The following clinicians are acknowledged for their clinical skill and for their participation in this study: C. Adibzadeh, K. Ahlfeldt, S. Bäckman, C. Bäckström, M. Bäckström, L. Enbom, S. Ericson, H. Eriksson, K. Gunnarsson, K. Isaksson, O. Larson, H. Lundström, B. Malm, I. Quick-Nilsson, J.-O. Nordberg, A. Nordin, G. Ramstedt, O. Ramstedt, J. Segerström, A. Sjöblom, L. Sjögren, G. Stroh, K. Sundin, L. Viklund, K. Zachrisson, B. Ödman, and L. Överby.

References

1. Rübeling S. Funkenerosion in der Zahntechnik. Möglichkeiten und Gränzen. Dent Labor 1982;30:1967.

2. Rübeling S, Kreylos H. Spark erosion in dental technology: possibilities and limitations. Quintessence Dent Technol 1984;8:649–57.
3. Stachniss V, Zimmer B. Funkenerosion—ein neuer Weg zu passgenauen Gussfüllungen und Kronen aus Edelmetall und edelmetallfreien Legierungen. Dtsch Zahnaerztl Z 1984;39:294.
4. Körber E, Lindemann W, Pielsticker W. Herstellung einer Schwebebrücke mit Hilfe der Funkenerosion. Die Quintessenz 1986; (Heft 10 Referat 6918):1689–94.
5. Körber E, Lindemann W, Pielsticker W. Herstellung einer Metallhülsenkrone aus Vollmaterial mit Hilfe der Funkenerosion. Dtsch Zahnaerztl Z 1986;41:525–6.
6. Lindemann W, Pielsticker W, Schiebel G. Inlayherstellung unter Einsatz der Funkenerosion. Dent Labor 1986;34:949–50.
7. Andersson M, Andersson M. Swedish Patent 8400396-1, 1987.
8. Cranin AN, Silverbrand H, Sher J, Satler N. The requirements and clinical performance of dental implants. In: Smith DS, Williams DF, eds. Biocompatibility of dental materials. Vol. IV. Boca Raton, Fla., USA: CRC Press, 1982; Chapter 10.
9. Albrektsson T, Zarb G, Worthington P, Eriksson AR. The long-term efficacy of currently used dental implants: a review and proposed criteria of success. Int J Oral Maxillofac Implants 1986;1:11–25.
10. Ryge G, Jendresen MD, Glantz P-O, Mjör I. Standardization of clinical investigators for studies of restorative materials. Swed Dent J 1981;5:235–9.
11. California Dental Association. Quality evaluation for dental care. Guidelines for the assessment of clinical quality and professional performance. Los Angeles: California Dental Association, 1977.
12. Lenox JA, Kopczyk RA. A clinical system for scoring a patient's oral hygiene performance. J Am Dent Assoc 1973;86:849–52.
13. Silness J. Periodontal conditions in patients treated with dental bridges. J Periodontol Res 1970;5:60–8.
14. Ekfeldt A, Øilo G. Occlusal contact wear of prosthodontic materials. An in vivo study. Acta Odontol Scand 1988;46:159–69.

Received for publication 30 May 1988