Implant Surface Coating and Bone Quality-Related Survival Outcomes Through 36 Months Post-Placement of Root-Form Endosseous Dental Implants

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Survival rates from placement to 36 months were reported for the ongoing Dental Implant Clinical Research Group studies of root-form endosseous dental implants. Failure rates for all implants were similar in bone qualities 1 and 2 (6.2% and 6.7%, respectively) and slightly higher in bone qualities 3 and 4 (8.5% and 8.7%, respectively). Hydroxyapatite (HA)-coated implants had an overall failure rate of 3.9% over 36 months in all bone qualities combined, while non-coated implants had a 13.4% failure rate for the same parameters. For each bone quality, there was a significant difference in implant survival for the non-coated implants (P <0.01). The highest failure rates for non-coated implants were in bone qualities 3 and 4 (19.1% and 25.5%, respectively). No major difference in survival was found for HA-coated implants placed in each bone quality. Possible reasons for the differences in survival are discussed. *Ann Periodontol 2000;5:109-118.*

KEY WORDS

Bone and bones; dental implant failure; dental implants; follow-up studies; hydroxyapatite/therapeutic use; osseointegration.

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Albrektsson and coworkers[1] reviewed six parameters critical to control for rigid fixation and proper osseointegration to occur: biocompatibility, design and surface conditions of the implant, condition of the recipient bone bed, surgical technique, and loading conditions. All of these are under the control of the clinician except bone quality. Debate continues among clinicians as to the ideal implant surface composition/conformation to maximize bone healing (osseointegration) and load transmission ability.

The long-term clinical success of titanium dental implants is reported to be highly influenced by both the quality and quantity of available bone.[2-9] For example, better bone quality and quantity in the anterior mandible are usually offered as the main reasons for higher survival rates of dental implants in lower jaws.[7,8,10] The percentage of bone-implant contact is higher in cortical bone than in cancelleous bone, which provides greater initial stability to the implant during the healing period following insertion. Stimulation of bone within physiologic limits may produce an increase in osseous density at the implant-bone interface.[11-15]

Other aspects of implant rehabilitation may be affected by bone quality. These

Table 1.
Study Strata, Implant Design, and Materials

Strata	N Implants	Implant Type	Implant Material
Mandibular fully edentulous	5 or 6	Basket* Screw† Cylinder‡	Titanium-alloy (Ti6AL4V–Grade 23, acid etched) Titanium-alloy (Ti6AL4V–Grade 23, acid etched) Titanium-alloy (Ti6AL4V–Grade23, acid-etched collar) HA-coated
Mandibular posterior partially edentulous	2 or 3	Basket* Cylinder‡	Titanium-alloy (Ti6AL4V–Grade 23, acid etched) Titanium-alloy (Ti6AL4V–Grade 23, acid-etched collar) HA-coated
Maxillary fully edentulous	5 or 6	Grooved§ Screw† Screw†	Titanium-alloy (Ti6AL4V–Grade 23, acid etched) HA-coated Titanium-alloy (Ti6AL4V–Grade 23, acid-etched collar) HA-coated Titanium-CP (Grade 3, acid etched)
Maxillary posterior partially edentulous	2 or 3	Grooved§ Cylinder‡	Titanium-alloy (Ti6AL4V–Grade 23, acid-etched) HA-coated Titanium-alloy (Ti6AL4V–Grade 23, acid-etched) HA-coated
Maxillary anterior single implant	1	Grooved§	Titanium-alloy (Ti6AL4V–Grade 23, acid-etched) HA-coated

* Core-Vent;† Screw-Vent;‡ Bio-Vent, § Micro-Vent, Core-Vent Corporation.

include drilling speed, pressure, and sequence; osteotomy size and use of a bone tap versus an osteotome; countersinking; length and number of implants placed; healing time; occlusal scheme; and the final prosthetic treatment plan.[16] Misch[13] has suggested that bone density also influences the rate of healing, and proposed time frames for the waiting periods between implant placement and delivery of the definitive prosthesis.

Bone volume (quantity) and relative bone density (quality) can be determined and quantified with computerized tomography scanning and other sophisticated radiological techniques. However, even following an appropriate presurgical diagnostic workup, the clinician should be prepared to encounter and manage any bone type. Prior knowledge of bone quality prevalence in various anatomical regions of the mouth will assist the clinician with the treatment planning and delivery stages of implant therapy, from selection of implant design to final prosthetic rehabilitation. Reports in the literature[17,18] suggest that surfaces other than machined, commercially pure titanium may be more successful in poor quality bone.

In 1991, clinicians and researchers from the Department of Veterans Affairs formed the Dental Implant Clinical Research Group (DICRG) to design and initiate a major comprehensive, multicenter, multidisciplinary, long-term clinical study to investigate the influence of implant design, application, and site of placement on clinical success.[19] The DICRG consists of 30 Department of Veterans Affairs medical centers and two research universities. Interim reports published in 1994[20] and 1997[21] reported on Stage 2 data for 1,935 and 2,633 implants, respectively. The aim of this report is to describe the distribution of survival/failures of hydroxyapatite (HA)-coated and non-coated root-form designs of one implant system in various types of bone quality for all enrolled study cases, totaling 2,762 individual fixtures, out to 36 months postuncovering.

MATERIALS AND METHODS

A total of 2,998 implants were placed and followed for a period of 36 months. As part of the comprehensive studies conducted by the DICRG, the quality of bone at each implant site was recorded at the time of implant placement surgery, and the prevalence of various bone qualities was later tabulated. The Lekholm-Zarb classification system[22] was used to assess bone quality.

Cases were assigned to one of five strata, designed to facilitate data analysis by implant location, degree of edentulism, and other baseline variables. The type of implant used in a given location was specific to the stratum but randomized for position within the stratum by the study design (Table 1). Implant length and diameter were determined by the treatment team.[19] The following implant types‖ were used:

1) Commercially pure titanium screw (Grade 3, acid etched with HF/NO_3), Ti-alloy screw (Ti6Al4V–Grade 23, acid etched with HF/NO_3), and titanium alloy screw (Ti6Al4V–Grade 23, with collar, acid etched with HF/NO_3) coated with hydroxyapatite (HA-coated-minimum crystallinity 62%, maximine porosity 5%): endosseous implant with externally threaded body and internal hex-thread connection with three materials options: commercially pure titanium (Grade 3, acid etched with HF/NO_3), titanium alloy (Ti6Al4V-Grade 23, acid etched with HF/NO_3), and titanium alloy (Ti-6Al4V-Grade 23, with collar, acid etched with HF/NO_3) coated with hydroxyapatite (minimum crystallinity 62%

‖ Core-Vent Corporation, DBA Paragon Company, Encino, CA.

and less than 5% porosity) coating; lengths 8, 10, 13, and 16 mm; diameters 3.5 mm (3.75 mm collar); finishing drill 3.2 mm.

2) Ti-alloy basket (Ti6Al4V–Grade 23, acid etched with HF/NO_3): titanium alloy endosseous implant with basket design and externally threaded body, and internal hex-thread connection; lengths 8, 10.5, 13, and 16 mm; diameters 4.3 mm at the threads (3.5 mm collar) and 5.3 mm at the threads (4.5 mm collar); finishing drills 3.5 and 4.5 mm.

3) HA-coated cylinder (Ti6Al4V–Grade 23, acid-etched collar with HF/NO_3) with hydroxyapatite coating (minimum crystallinity 62%, less than 5% porosity): HA-coated endosseous implant with cylindrical body and internal hex-thread connection; lengths 8, 10.5, 13, and 16 mm; diameters 3.5 mm and 4.5 mm; finishing drills 3.5 mm and 4.5 mm.

4) HA-coated grooved (Ti6Al4V–Grade 23, acid-etched HF/NO_3 collar) with hydroxyapatite (minimun crystallinity 62%, less than 5% porosity): HA-coated endosseous implant with ledged body design, vertical grooves, and internal hex-thread connection; lengths 7, 10, 13, and 16 mm; diameters 3.25 mm (3.5 mm collar) and 4.25 mm (4.5 mm collar); finishing drills 2.5/3.2 and 3.0/4.2 mm diameters.

Implants were placed according to the manufacturer's surgical protocol. At implant insertion, the following data were recorded on standardized forms: implant type, diameter, and length; site of placement (tooth number); type of restoration planned; type of incision (crestal/remote); use of bone tap (yes/no); medications prescribed (analgesics/antibiotics/other); snugness of fit (firm/loose); and bone quality (BQ 1-4).

Bone quality was assessed by a combination of radiographic density and subjective clinical evaluation during osteotomy preparation. Additional bone measurements were also recorded including width of buccal and lingual bone (after crestal reduction if necessary to provide for a minimum of 1 mm of bone on buccal/lingual surfaces), distance between the bone crest and the top of the implant, and the distance between implants.

Following a recommended submerged healing period of at least 3 months for the mandible and 6 months for the maxilla, the implants were uncovered and the following data recorded on standardized forms: type of exposure incision (crestal/remote/punch); distance between bone crest and top of implant; clinical status of osseointegration by manual mobility testing (presence or absence of rotational movement when attaching healing cap and Periotest[¶] values for mobility).

Implants removed at any stage of treatment were recorded as failures. Stage 1 was from the time of placement up to uncovering. Stage 2 was at the time of uncovering. (Note: The healing period included both Stage 1 and 2 failures). Stage 3 was prior to delivery of the final prosthesis, and Stage 4 was post-loading of the final prosthesis.

Table 2.

Survival of All Implants (includes all HA-coated and non-coated implants) to 36 Months by Bone Quality

Bone Quality (N)	N Survive (Fail)	% Survive (% Fail)
BQ-1 (258)	242 (16)	93.8 (6.2)
BQ-2 (1,387)	1,294 (93)	93.3 (6.7)
BQ-3 (1,100)	1,007 (93)	91.5 (8.5)
BQ-4 (253)	231 (22)	91.3 (8.7)

This project was first reviewed and approved by the Research and Development Committee and Human Studies Committee of the project office (DVAMC, Ann Arbor, Michigan). In addition, appropriate local review and approval were received by each participating medical center.

Statistical Methods

Survival outcomes were compared for all implants using descriptive data. Differences in survival outcomes for each bone quality and for the two implant types (HA-coated versus non-coated) were compared using survival curves.

RESULTS

Survival of All Implants

The data presented here represent longitudinal follow-up data of DICRG results published previously.[20,21] The results are summarized in Tables 2 through 4, and survival curves are shown in Figures 1 through 6.

A total of 258 (8.6%) implants were placed in BQ-1; 1,387 (46.3%) in BQ-2; 1,100 (36.6%) in BQ-3; and 253 (8.6%) in BQ-4 and followed for 36 months. Table 2 presents the distribution of implant survival (failures %) recorded for all implants combined (HA plus non-coated) by bone quality after 36 months. Overall survival of all implants placed and followed for a period of 36 months was 92.6% (2,774/2,998). Total implant survival in BQ-1 from the time of placement to 36 months was 93.8% (6.2% failures). In BQ-2, survival from placement to 36 months was 93.3% (6.7% failures); for BQ-3, 91.5% (8.5% failures) of the implants placed survived to 36 months; and the total survival from placement to 36 months for BQ-4 was 91.3 (8.7% failures). As the bone quality decreased, there was a slight reduction in implant survival, which was less in “good bone” (BQ-1 and BQ-2) and greater in “poor bone” (BQ-3 and BQ-4).

¶ Siemens AG, Bensheim, Germany.

Overall survival of all HA-coated implants followed for a period of 36 months was 96.1% compared to 86.5% for non-coated implants. Survival of the HA-coated implants was not found to be significantly better for any of the bone qualities (Fig. 1). The opposite was true for non-coated implants (Fig. 2). As the bone quality decreased, there was a significant increase in the failures (*P*<0.001, log rank, Breslow and Tarone-Ware).

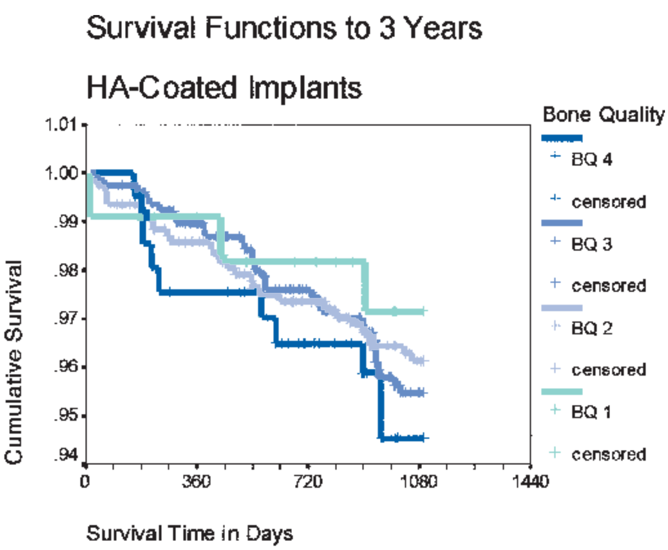

Figure 1.
Survival curves; survival of HA-coated implants from placement to 36 months in each bone quality. Survival was not found to be significantly better in any one of the bone qualities (P >0.05, log rank, Breslow and Tarone-Ware).

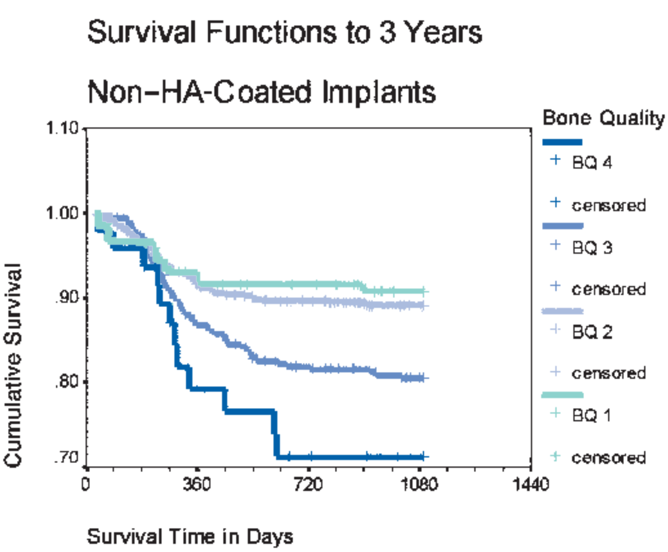

Figure 2.
Survival curves; survival of non-coated implants in each bone quality from placement to 36 months. As the bone quality decreased, there was a statistically significant decrease in the survival of non-coated implants (P <0.001, log rank, Breslow and Tarone-Ware).

HA-Coated Versus Non-Coated Implant Survival

One of the biggest controversies in implant dentistry today is the performance of HA-coated compared to non-coated implants. Table 3 presents a breakdown of survival/failures by implant surface (HA-coated or non-coated) in various bone densities after 36 months. For all bone qualities, HA-coated implants demonstrated a significantly higher survival rate than non-coated implants out to 36 months (Tables 3 and 4, Figs. 3 through 6). As the bone quality decreased, the area between the two survival curves became greater (Figs. 3 through 6). This area graphically illustrates the magnitude of the difference in survival over time between the two implant types.

Table 4 provides more detailed data regarding the timing of implant failures out to 36 months, broken down again by bone quality, surface coating, and stage at which failure occurred. Non-coated implants were more often associated with early failures (5.6%) during the healing period (Stages 1 and 2 combined), compared to 1.1% for HA-coated implants. This pattern was evident for each of the bone quality categories.

Bone Quality-1

All implants placed in BQ-1 had early failures before uncovering (Stage 1) of 2.3% (6/258), and at uncovering (Stage 2), another 1.2% failed (3/258) and were removed. Combining Stages 1 and 2 together provides information about survival during the healing period:

Table 3.

Survival of All Implants to 36 Months by Bone Quality: HA Versus Non-HA (descriptive data)

Bone Quality	N Survive	% Survive
BQ-1 (N = 258)		
HA (111/258) = 43%	108/111	97.3
Non-HA (147/258) = 57%	134/147	91.2
BQ-2 (N = 1,387)		
HA (778/1,387) = 56.1%	750/778	96.4
Non-HA (603/1,387) = 43.4%	544/609	89.3
BQ-3 (N = 1,100)		
HA (780/1,100) = 70.9%	748/780	95.9
Non-HA (320/1,100) = 29.1%	259/320	80.9
BQ-4 (N = 253)		
HA (206/253) = 81.4%	196/206	95.1
Non-HA (47/253) = 18.6%	35/47	74.5
Total	2,774/2,998	92.6

Table 4.

Timing of Implant Failures to 36 Months by Bone Quality and Surface Coating

Coating/Stage	BQ-1	BQ-2	BQ-3	BQ-4	Table Total
HA-Coated					
Surviving	108/111 = 97.3%	750/778 = 96.4%	748/780 = 95.9%	196/206 = 95.1%	1,802/1,875 = 96.1%
Failures					
Stage 1	1/0.9%	7/1.0%	2/0.3%	-	10/0.5%
Stage 2	-	3/0.4%	4/0.5%	4/1.9%	11/0.6%
(Healing period)*	(1/0.9%)	(10/1.3%)	(6/0.8%)	(4/1.9%)	(21/1.1%)
Stage 3	1/1.0%	6/0.8%	7/0.9%	4/1.9%	18/0.9%
Stage 4	1/0.9%	12/1.5%	19/2.4%	2/1.0%	34/1.8%
Total HA	3/2.7%	28/3.6%	32/4.1%	10/4.9%	73/3.9%
Non-Coated					
Surviving	134/147 = 91.2%	544/609 = 89.3%	259/320 = 80.9%	35/47 = 74.5%	972/1,123 = 86.6%
Failures					
Stage 1	5/3.4%	11/1.8%	2/0.6%	1/2.1%	19/1.7%
Stage 2	3/2.0%	20/3.3%	18/5.6%	3/6.4%	44/3.9%
(Healing period)*	(8/5.4%)	(31/5.1%)	(20/6.3%)	(4/8.5%)	(63/5.6%)
Stage 3	4/2.7%	23/3.8%	26/8.1%	7/14.9%	60/5.3%
Stage 4	1/0.7%	11/1.8%	15/4.6%	1/2.1%	28/2.5%
Total non-coated	13/8.8%	65/10.7%	61/19.1%	12/25.5%	151/13.4%

* Healing period = Stages 1 and 2 combined.

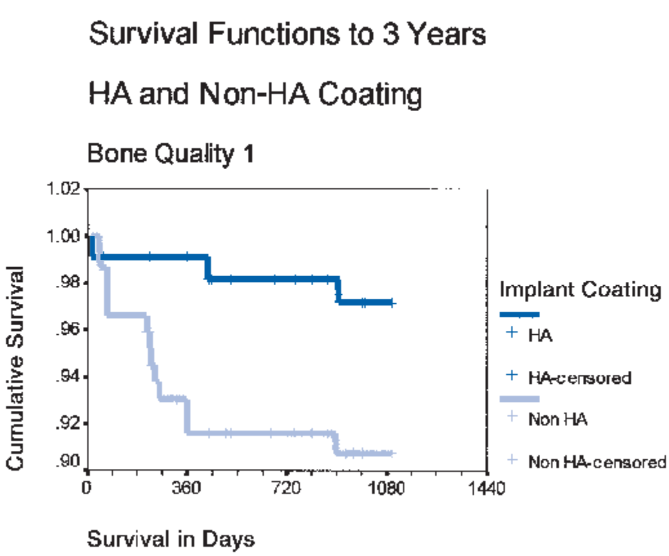

Figure 3.
Survival curves. Survival of HA-coated and non-coated implants placed in bone quality-1 and followed from placement to 36 months. At each evaluation period, the HA-coated implants showed significantly better survival than non-coated implants (P <0.001, log rank, Breslow and Tarone-Ware).

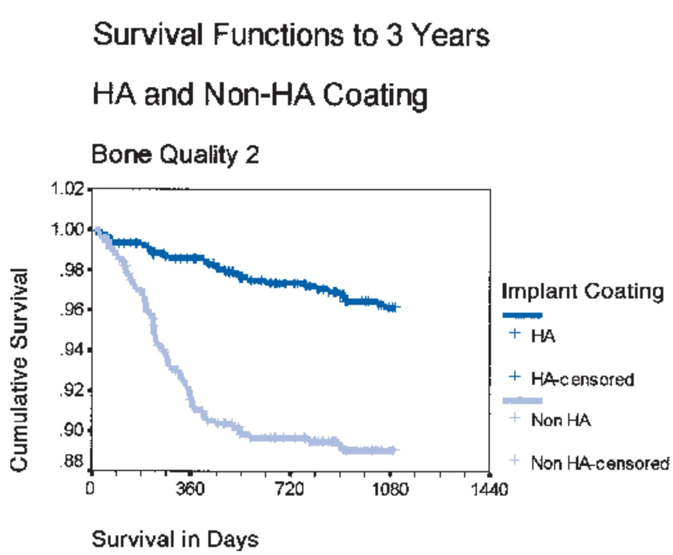

Figure 4.
Survival curves. Survival of HA-coated and non-coated implants placed in bone quality-2 and followed from placement to 36 months. At each evaluation period, the HA-coated implants showed significantly better survival than non-coated implants. (P <0.001, log rank, Breslow and Tarone-Ware).

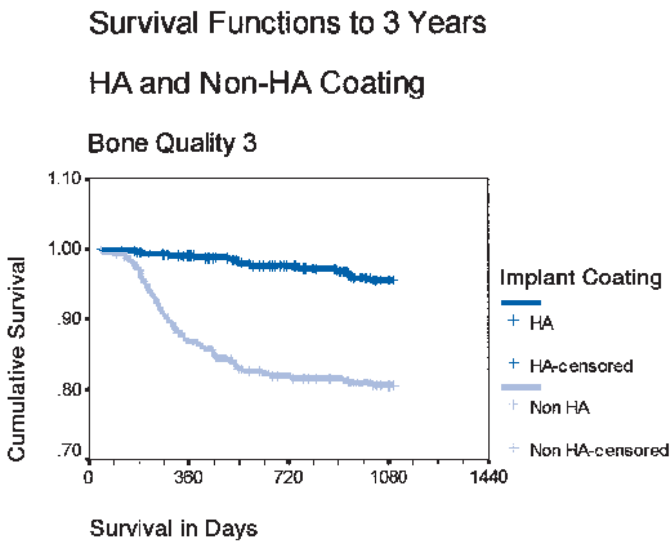

Figure 5.
Survival curves. Survival of HA-coated implants and non-coated implants placed in bone quality-3 and followed from placement to 36 months. At each evaluation period, the HA-coated implant showed significantly better survival than non-coated implants (P <0.001, log rank, Breslow and Tarone-Ware).

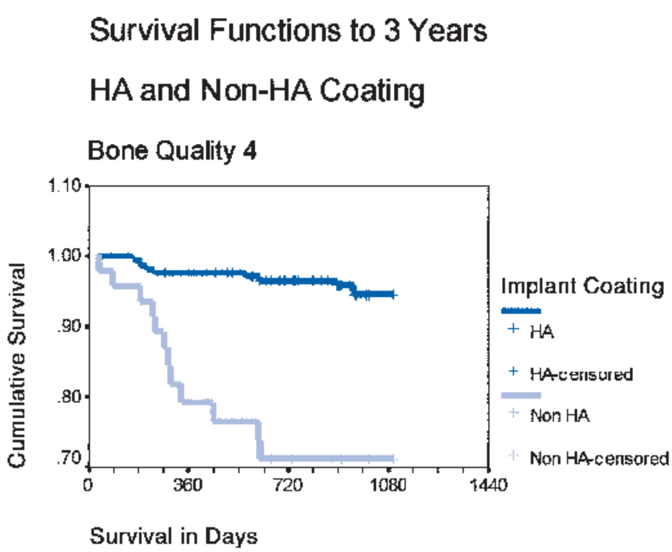

Figure 6.
Survival curves. Survival of HA-coated and non-coated implants placed in bone quality-4 and followed from placement to 36 months. At each evaluation period, the HA-coated implants showed significantly better survival than non-coated implants (P <0.001, log rank, Breslow and Tarone-Ware).

3.5% (9/258) of the implants were removed in this bone density category. The removals during the healing period consisted largely of non-coated implants (Table 4, Fig. 3). Following uncovering but before the placement and loading of the prosthesis (Stage 3), one HA-coated and four non-coated implants failed (5/238 = 2.1%) and were removed. Following loading of the prosthesis up to 36 months (Stage 4), an additional 0.8% (2/258) of all implants were removed (Table 4). Of these, 0.9% (1/111) were HA-coated compared to 0.7% (1/147) that were non-coated.

Of the 258 implants placed in BQ-1 and followed for 36 months, 43% of these were HA-coated and 57% were non-coated (Table 3). During the Stage 1 period, 0.9% (1/111) of the HA-coated implants failed, compared to 3.4% (5/147) of the non-coated implants (Table 4). An additional 2.0% of non-coated implants failed at the time of Stage 2 uncovering, giving a total of 5.4% for the healing period (Table 4); however, no failures occurred for the HA-coated implants in this same time period. Following uncovering, but before placement and loading of the prosthesis (Stage 3), HA-coated implants experienced 1% failures compared to 2.7% for the non-coated implants. After placement and loading of the prosthesis to 36 months, 0.9% (1/111) of the HA-coated implants failed compared to 0.7% (1/147) for the non-coated implants. Total overall survival from placement to 36 months was 97.3% for all HA-coated implants and 91.2% for the non-coated. Non-coated implants were approximately 2 to 3 times more likely to fail in BQ-1 than HA-coated implants out to 36 months, which was statistically significant (Fig. 3) (P <0.001, log rank, Breslow and Tarone-Ware).

Bone Quality-2

Of all implants placed in BQ-2, the early failures from placement to uncovering (Stage 1) for all implants placed were 1.3% (18/1,387), which increased at uncovering (Stage 2) with an additional 1.7% (23/1,387) failing. Total failures during Stages 1 and 2 combined was 3.0% (41/1,387). Before placement of the prosthesis (Stage 3), 2.1% (29/1,387) more implants failed; following placement and loading of the prosthesis (Stage 4), 1.7% (23/1,387) of the implants failed out to 36 months.

In BQ-2, 56.1% of the implants placed were HA-coated and 43.4% were non-coated (Table 3). In the early stage of healing (Stage 1) but before uncovering, 1.0% (7/778) of the HA-coated implants failed and were removed compared to 1.8% (11/609) for non-coated implants (Table 4). Non-coated implants were nearly twice as likely to fail as HA-coated implants during this critical period. At Stage 2 uncovering, 0.4% (3/778) more HA-coated implants failed and were removed compared to 3.3% (20/609) failures for the non-coated implants. Non-coated implants were almost 8 times more likely to fail at uncovering as those that were HA-coated. In the combined Stage 1 and 2 periods, total failures (10/778) were 1.3% for HA-coated implants and 5.1% (31/609) for the non–HA-coated implants (Table 4). Following uncovering but before placement and loading of the prosthesis (Stage 3), 0.8% (6/778) of the HA-coated implants failed, compared to 3.8% (23/609) for non-coated implants. After loading of the prosthesis to 36 months (Stage 4), 1.5% (12/778) of the HA-coated implants failed, and 1.8% (11/609) of the non-coated implants failed. Total failures from placement to 36 months of function for the HA-coated implants was 3.6% (96.4% survival) and 10.7% (89.3% survival) for non HA-implants. Non-coated implants were approximately 3 times at more risk of failure compared to HA-coated implants out to 36 months in BQ-2. The HA-coated implant survival in BQ-2 was significantly better than non-coated implants (Fig. 4, $P<0.001$, log rank, Breslow, and Tarone-Ware).

Bone Quality-3

In BQ-3, early failures following placement to the time of uncovering (Stage 1) for all implants combined was 0.4% (4/1,100). At uncovering (Stage 2), an additional 2.0% (22/1,100) of all implants failed. For the entire healing period (Stages 1 and 2), a total of 2.4% (26/1,100) of the implants were removed. Following uncovering but before placement and loading of the prosthesis (Stage 3), 3.0% (33/1,100) more failures occurred. Following loading of the prosthesis (Stage 4), 3.1% (34/1,100) additional implants were removed. For all stages of treatment, the total failures in BQ-3 were 8.5% (93/1,100), with 91.5% of the implants surviving.

In BQ-3, 70.9% of the implants were HA-coated and 29.1% were non-coated (Table 3). Prior to uncovering (Stage 1), HA-coated implants failed 0.3% (2/780) of the time and non-coated implants 0.6% (2/320). At uncovering (Stage 2), an additional 0.5% (4/780) of the HA-coated implants failed, while the non-coated implants incurred an additional 5.6% (18/320) failure rate. This provided a total failure rate during healing (Stages 1 and 2) of 0.8% for HA-coated implants and 6.3% for non-coated implants. Non-coated implants were at 7 to 8 times greater risk of failure in this bone density during the healing period (Table 4). Before loading of the prosthesis (Stage 3), 0.9% (7/780) of the HA-coated implants failed compared to 8.1% (26/320) for non-coated. At this stage of treatment, the non-HA implant was almost 8 times more likely to fail than an HA-coated implant. Following loading to 36 months (Stage 4), the HA-coated implant failures increased to 2.4% (19/780), which was less than the 4.6% (15/320) failure rate for the non-coated implants. Non-coated implants were slightly more at risk of experiencing early failures. The total failures from placement to 36 months were 4.1% (95.9% survival) for HA-coated implants and 19.1% (80.9% survival) for non-coated implants (Table 3). Non-coated implants were about 4 to 5 times more at risk of failure as HA-coated implants in BQ-3 loaded out to 36 months.

Bone Quality-4

In BQ-4, early failures during the healing period of placement to uncovering (Stage 1) were 0.4% (1/253) and an additional 2.8% (7/253) at uncovering (Stage 2). The total for this healing period (Stages 1 and 2) was therefore 3.2% (8/253). From uncovering up to placement of the prosthesis (Stage 3), an additional 4.3% (11/253) of the implants failed and were removed, while from loading to 36 months, 1.2% (3/253) failed and were removed. Overall, the total failures from placement to uncovering were 22/253 or 8.7% (91.3% survival) for BQ-4 (Tables 3 and 4).

In BQ-4, 81.4% of the implants placed were HA-coated, while only 18.6% were non-coated implants (Table 3). Early failures following placement (Stage 1) were 2.1% (1/47) for non-coated implants, while 100% of the HA-coated implants survived. At the time of uncovering (Stage 2), 1.9% (4/206) of the HA-coated implants failed and were removed, compared to 6.4% (3/47) of the non-coated implants. For the combined healing period from placement to uncovering (Stages 1 and 2), the total failures were 1.9% (4/206) for the HA-coated implants and 8.5% (4/47) for the non-coated designs. Before the placement of the prosthesis (Stage 3), an additional 1.9% (4/206) of the HA-coated implants failed compared to 14.9% (7/47) for the non-coated implants. Following loading of the prosthesis to 36 months (Stage 4), HA-coated implants failed 1.0% (2/206) of the time and non-coated implants 2.1% (1/47) of the time. Total failures from implant placement to 36 months for HA-coated implants were 4.9% (95.1% survival) and 25.5% (74.5% survival) for non-coated implants. Non-coated implants experienced 5 to 6 times greater risk of failure than HA-coated implants.

DISCUSSION

Manufacturers and clinicians are considering the importance of bone quality and shape in relation to the design, surface characteristics, and placement techniques of dental implants. Engquist et al. placed 191 maxillary and 148 mandibular implants (Nobelpharma, AN, Göteborg, Sweden) supporting overdentures.[9] Of the 38 maxillary implants (20%) that failed to osseointegrate at uncovering, 31 were in Q-4 bone, with 78% of the total implant failures occurring in Q-4 bone. The loss of 23 of 52 Brånemark implants (44%) placed in Q-4 bone in the maxilla; 11 of 30 implants (37%) placed in Q-4 bone in the posterior mandible; and 2 of 20 (10%) implants placed in Q-4 bone anterior to the mental foramina was reported by Jaffin and Berman, for an overall failure rate of 35% in Q-4 bone.[7] They experienced only a 3% loss at the time of uncovering of all implants placed in Q-1 to Q-3 bone. This 3% loss is similar to the current DICRG data for all non-coated implants at uncovering in bone qualities 1 through 3. To overcome some of these difficulties, Nobelpharma introduced self-tapping implants in 1983 for use in situations where soft bone quality is present.[23] The company continued with further modifications and developed a wider diameter fixture (5.0 mm) that Langer et al.[24] described as useful in areas of poor bone quality. Wider implants may increase interfacial bicortical stabilization.

Recognizing that surface roughness may play a role in the mechanical attachment of an implant surface to bone, hydroxyapatite, titanium plasma sprayed, and titanium acid-etched or blasted implant surfaces have been developed to improve osseointegration, compared to machined CP titanium screw fixtures, when placed in poor quality bone. Lozada[25] reported on the success or failure of 109 uncoated titanium screw implants (Steri-Oss) and 110 HA-coated titanium screw implants (Steri-Oss) in what he classified as type 4 bone. In the maxillary arch, 32.6% of uncoated implants failed compared to 14.7% for the HA-coated implants. The DICRG data at 3 years approaches similar numbers for non-coated failures in BQ-4 (24.4%), but only 4.1% of HA-coated implants in BQ-4. Differences in survival for HA-coated implants in the DICRG database may be due to 3- versus 5-year data, differences in HA coatings, and the inclusion of grooved and cylindrical HA-coated designs along with HA-coated screws. The Spectra-System contains implants of several designs and surface characteristics reportedly intended to meet the needs of different bone qualities and shapes found in the various jaw locations. Saadoun and LeGall[17] studied 673 Steri-Oss (Denar) implants (titanium screws, HA titanium screws, and HA-titanium cylinders) during a 5-year period and recommended the choice of design be based on implant lengths, bone quality, and anatomic region. They recommended that the closer the bone is to type 4, the greater the indication for HA-titanium cylinders. Fugazotto et al.[18] placed a total of 1,363 titanium plasma-sprayed, cylindrical implants (IMZ, Interpore, Irvine, CA), 513 of which were inserted in Q-4 bone. The success rate dropped from 97.4% overall to 95.7% for Q-4 bone (22 failures in Q-4 bone out of a total of 34).

Kent et al.[26] and Babbush and Shimura[27] reported success rates after 5 years of 95% for HA-coated cylinders. Hahn and Vassos[28] recently reported a 97.8% survival rate after 6 years for HA-coated cylinders. For HA-coated threaded implants, Lozada[25] reported a 95% success rate retrospectively after 8 years, while Buchs et al.[29] experienced a 96% success rate 5 years post-restoration. Again, this is very similar to the DICRG data indicating 95.9% survival of HA-coated designs at 36 months.

Clinical predictability and indications for use of HA-coated implants remain controversial. In contrast to the above reports, Wheeler[30] experienced increasing failure rates of HA-coated cylinders several years post-restoration. Wheeler ascribed these failures to peri-implantitis, with clinical findings of mild to severe soft tissue changes and bone loss. Reports in the literature[31,32] have suggested that HA coatings are unstable, are more susceptible to bacterial infection, may be predisposed to rapid osseous breakdown, and do not demonstrate significant advantages over titanium implants.

Morphologic studies (SEM) of subgingival plaque maturation on HA, titanium, and cementum surfaces failed, however, to show any differences in the maturation sequences of bacterial morphotypes by surface composition.[33]

Paschalis and coworkers[34] concluded that various commercial coatings labeled as "HA" behave differently when exposed to identical in vitro environments and that it is conceivable that HA may respond differently along different sites of the implant as the local environment varies in the same patient. Similar conclusions were reached by Gross et al.[35] who reported preferential dissolution of the amorphous phase of HA, compared to cracking of the more crystalline phase of HA, presumably secondary to release of internal stresses. Loss or fracture of the HA-coating is a concern,[36] particularly for press-fit versus threaded designs. This effect on the surface integrity of HA-coated threaded implants was reported by Edmonds and colleagues.[37] Increased amounts of HA surface damage were documented for implants inserted into undersized sites. It was felt that this damage occurred due to the increased friction and force required to seat the implants to position. Fortunately, reports of in vivo fractures at the HA-titanium interface are extremely rare.[34,38]

In another article, Gross and coworkers[39] characterized the locations of the amorphous and crystalline phases on HA-coated implants. Coatings from commercially available HA-coated implants demonstrated a gradient of crystallinity from more amorphous at the implant-coating interface, to more crystalline at the coating surface, particularly at the distal ends of the implants and at the thread apices. It was explained that the higher crystallinity was due to increased heat buildup in these areas at the time of plasma spraying. The authors suggested that the opposite pattern may be more beneficial, with more amorphous HA on the surface to speed initial healing, and more crystalline HA at the implant interface to increase interfacial bonding strength. The pattern reported by Gross et al.[39] may explain why HA-coated implants function well for approximately 3 to 5 years and then begin to experience a drop-off in survival as the crystalline surface slowly resorbs, until the amorphous layer at the implant interface is reached, which then undergoes more rapid dissolution, leading to loss of the implant.

A critical paradox is created, therefore, by the different biological properties of HA coatings with varying solubilities: calcium phosphate-coated implant surfaces should allow biodegradation to enhance bone response[40,41] but not complete dissolution, which would result in loss of mechanical stability at the implant-HA interface.[42,43]

The DICRG database will continue to be monitored as the cases mature through 5 years and beyond to determine whether there is any change in the survival status for HA-coated implants.

CONCLUSIONS

Analysis of 2,998 root-form implants placed by the DICRG investigators and followed for 36 months suggests subtle differences in failure rates among various bone qualities. Quality-1 bone experienced the lowest failure rate (6.2%), followed closely by Q-2 (6.7%). The failure rate for Q-3 bone was 8.5%, while Q-4 bone was 8.7%. There was a trend for an increasing percentage of failures in less dense bone qualities, with a dichotomous split between BQ-1 and 2 and BQ-3 and 4.

The quality of bone was not an important predictor of implant success overall in the current data. A far more important discriminator of implant survival was surface coating used with various bone qualities, with HA-coating demonstrating an increasing benefit as bone quality decreased. Overall, survival of HA-coated implants was 96.1% at 36 months, with 95.1% surviving in BQ-4. Additional factors such as implant length, experience of the operator in patient selection,[1] surgical skill/experience,[44,45] and healing time prior to exposure[14] may be as important as surface coating and its influence on success rates of root-form implants, and more important than bone quality, out to 36 months.

REFERENCES

1. Albrektsson T, Brånemark P-I, Hansson HA, Lindström J. Osseointegrated titanium implants. Requirements for ensuring a long-lasting direct bone anchorage in man. *Acta Orthop Scand* 1981;52:155-170.
2. Jemt T, Lekholm U. Implant treatment in edentulous maxillae: A five-year follow-up report on patients with different degrees of jaw resorption. *Int J Oral Maxillofac Implants* 1995;10:303-311.
3. Higuchi KW, Folmer T, Kultje C. Implant survival rate in partially edentulous patients. A 3-year prospective multicenter study. *J Oral Maxillofac Surg* 1995;53:264-268.
4. Mericske-Stern K. Overdentures with roots or implants for elderly patients. A comparison. *J Prosthet Dent* 1994; 72:543-550.
5. Bahat O. Treatment planning and placement of implants in the posterior maxillae: Report of 732 consecutive Nobelpharma implants. *Int J Oral Maxillofac Implants* 1993;8:151-161.
6. Johns RB, Jemt T, Heath MR, et al. A multicenter study of overdentures supported by Brånemark implants. *Int J Oral Maxillofac Implants* 1992;7:513-522.
7. Jaffin R, Berman C. The excessive loss of Brånemark fixtures in type IV bone: A 5-year analysis. *J Periodontol* 1991;62:2-4.
8. Friberg B, Jemt T, Lekholm U. Early failures in 4,641 consecutively placed Brånemark dental implants: A study from stage 1 surgery to the connection of completed prostheses. *Int J Oral Maxillofac Implants* 1991;6:142-146.
9. Engquist B, Bergendal T, Kallus T, Linden U. A retrospective multicenter evaluation of osseointegrated implants supporting overdentures. *Int J Oral Maxillofac Implants* 1988;3:129-134.
10. Bass SL, Triplett RG. The effects of preoperative resorption and jaw anatomy on implant success. *Int J Oral Maxillofac Implants* 1991;6:193-198.
11. Morris HF, Ochi S, Gillette W, et al. Bone quality and implant integration during follow-up in the DICRG clinical study. *J Dent Res* 1995;74(Spec. Issue):495(Abstr. 753).
12. Arpak N, Neidermeier W, Nergiz I, Schulz A, Bostanci H. Morphometry of the periimplant of immediate and late endosseous implants. *J Dent Res* 1994;73(Spec. Issue):414(Abstr. 110).
13. Misch CE. Density of bone: Effect on treatment plans, surgical approach, healing and progressive bone loading. *Int J Oral Implantol* 1990;6:23-31.
14. Carter DR. Mechanical loading histories and cortical bone remodeling. *Calcif Tissue Int* 1984;36(Suppl. 1):S19-S24.
15. Carter DR, Caler WE. Cycle-dependent and time-dependent bone fracture with repeated loading. *J Biomech Eng* 1983;105:166-170.
16. Misch CE. *Contemporary Implant Dentistry*. St. Louis: CV Mosby; 1993:469-485.
17. Saadoun AP, LeGall ML. Clinical results and guidelines on Steri-Oss endosseous implants. *Int J Periodontics Restorative Dent* 1992;12:487-499.
18. Fugazotto PA, Wheeler SL, Lindsay JA. Success and failure rates of cylinder implants in type IV bone. *J Periodontol* 1993;64:1085-1087.
19. Morris H, Ochi S. The influence of implant design, application, and site on clinical performance and crestal bone: A multicenter, multidisciplinary clinical study. *Implant Dent* 1992;1:49-55.
20. Truhlar RS, Morris HF, Ochi S. Second-stage failures related to bone quality in patients receiving endosseous dental implants: DICRG interim report no. 7. *Implant Dent* 1994;3:252-255.
21. Truhlar RS, Farish SE, Scheitler LE, Morris HF, Ochi S. Bone quality and implant design-related outcomes through Stage 2 surgical uncovering of Spectra-System root form implants. *J Oral Maxillofac Surg* 1997; 55(Suppl. 5):46-54.
22. Lekholm U, Zarb GA. Patient selection and preparation. In: Brånemark P-I, Zarb GA, Albrektsson T, eds. *Tissue-Integrated Prostheses: Osseointegration in Clinical Dentistry*. Chicago: Quintessence; 1985:199-209.
23. Friberg B, Grondahl K, Lekholm U. A new self-tapping Brånemark implant: Clinical and radiographic evaluation. *Int J Oral Maxillofac Implants* 1992;7:80-85.
24. Langer B, Langer L, Herrmann I, Jorneus L. The wide fixture: A solution for special bone situations and a rescue for the compromised implant. *Int J Oral Maxillofac Implants* 1993;8:400-408.
25. Lozada JL. Eight-year clinical evaluation of HA-coated

implants. *J Dent Symp* 1993;1:67-69.
26. Kent JN, Block MS, Finger IM, et al. Biointegrated hydroxylapatite-coated dental implants: 5-year clinical observations. *J Am Dent Assoc* 1990;121:138-144.
27. Babbush CA, Shimura M. Five-year statistical and clinical observations with the IMZ two-stage osseointegrated implant system. *Int J Oral Maxillofac Implants* 1993; 8:245-253.
28. Hahn J, Vassos DM. Long-term efficacy of hydroxyapatite-coated cylindrical implants. *Implant Dent* 1997;6: 111-115.
29. Buchs AU, Hahn J, Vassos DM. Interim clinical study report: A threaded, hydroxylapatite-coated implant–five year post-restoration safety and efficacy. *J Oral Implantol* 1995;21:266-274.
30. Wheeler SL. Eight-year clinical retrospective study of titanium plasma-sprayed and hydroxyapatite-coated cylinder implants. *Int J Oral Maxillofac Implants* 1996;11: 340-350.
31. Johnson BW. HA-coated dental implants: Long-term consequences. *J Calif Dent Assoc* 1992;20:33-41.
32. Albrektsson T, Sennerby L. State of the art in dental implants. *J Clin Periodontol* 1991;18:474-481.
33. Gatewood RR, Cobb CM, Killoy WJ. Microbial colonization on natural tooth structure compared with smooth and plasma-sprayed dental implant surfaces. *Clin Oral Implants Res* 1993;4:53-64.
34. Paschalis EP, Zhao Q, Tucker BE, et al. Degradation potential of plasma-sprayed hydroxyapatite-coated titanium implants. *J Biomed Mater Res* 1995; 29:1499-1505.
35. Gross KA, Berndt CC, Goldschlag DD, Iacono VJ. In vitro changes of hydroxyapatite coatings. *Int J Oral Maxillofac Implants* 1997;12:589-597.
36. Spivak JM, Ricci JL, Blumenthal NC, Alexander H. A new canine model to evaluate the biological response of intramedullary bone to implant materials and surfaces. *J Biomed Mater Res* 1990;24:1121-1149.
37. Edmonds RM, Yukna RA, Moses RL. Evaluation of the surface integrity of hydroxyapatite-coated threaded dental implants after insertion. *Implant Dent* 1996;5:273-278.
38. Lewandowski JA, Johnson CM. Structural failure of osseointegrated implants at the time of restoration. A clinical report. *J Prosthet Dent* 1989;62:127-129.
39. Gross KA, Berndt CC, Iacono VJ. Variability of hydroxyapatite-coated dental implants. *Int J Oral Maxillofac Implants* 1998;13:601-610.
40. Orly I, Gregoire M, Menanteau J, et al. Effects of synthetic calcium phosphates on the ^{3}H-thymidine incorporation and alkaline phosphatase activity of human fibroblasts in culture. *J Biomed Mater Res* 1989;23:1433-1440.
41. Ducheyne P, Beiht J, Cuckla J, et al. Effect of calcium phosphate coating characteristics on early post-operative bone tissue ingrowth. *Biomaterials* 1990;11:531-540.
42. Cook SD, Kay JF, Thomas KA, Jarcho M. Interface mechanics and histology of titanium and hydroxyapatite-coated titanium for dental implant applications. *Int J Oral Maxillofac Implants* 1987;2:15-22.
43. Kay F. Bioactive surface coatings: Cause for encouragement and caution. *J Oral Implantol* 1988;14:43-54.
44. Adell R, Lekholm U, Brånemark P-I. Surgical procedures. In: Brånemark PI, Zarb GA, Albrektsson T, eds. *Tissue-Integrated prostheses: Osseointegration in Clinical Dentistry*. Chicago: Quintessence; 1985:211-232.
45. Lambert PM, Morris HF, Ochi S. Positive effect of surgical experience with implants on second-stage implant survival. *J Oral Maxillofac Surg* 1997;5(Suppl. 5):12-18.

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