A Comparison of Endosseous Dental Implant Surfaces*

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Endosseous dental implants are available with various surface characteristics ranging from relatively smooth machined surfaces to more roughened surfaces created by coatings, blasting by various substances, by acid treatments, or by combinations of the treatments. Studies characterizing these implants and surfaces include in vitro experimentation, animal studies, and human clinical trials. Both descriptive and functional testing of the bone-implant interface includes histomorphometrics and biomechanical testing such as torque removal values and push out/pull out strength. Using these assays to evaluate and compare different surfaces, the data demonstrate that rough implant surfaces have increased bone-to-implant contact and require greater forces to break the bone-implant interface compared to more smooth surfaces. The objective of this report was to evaluate publications of human clinical experiences evaluating implant use in patients and to determine if differences existed in success rates of implants with relatively smooth surfaces compared to implants having roughened implant surfaces. Human trials were reviewed to determine the clinical efficacy of implants under various clinical indications. Synopsis tables were constructed and the experiences segregated by implant surface characteristics. Meta-analyses were performed on all implants in all locations, on implants placed only in the maxilla or the mandible, and, finally, on implants placed in the maxilla compared to implants placed in the mandible. Evaluation of the data revealed that predictably high success rates can be achieved for implants with both rough and smooth titanium surfaces and for hydroxyapatite-coated implants. When studies were clustered by specific indications or patient populations, rough surfaced implants had significantly higher success rates compared to implants with more smooth surfaces except in the case of single tooth replacements where the success rates were comparable. In general, implants placed in the mandible had significantly higher success rates than implants placed in the maxilla. However, in the partially edentulous patient group, titanium implants with a rough surface had significantly higher success rates in the maxilla compared to the mandible and, in cases of single tooth replacement, success rates were similar in the maxilla and in the mandible as was the case for hydroxyapatite-coated implants. The documented advantage of implants with a roughened surface in animal and in vitro experiments has been demonstrated in clinical cases when studies were compared in which specific indications or patients were treated. Additionally, implants placed in the mandible have, in general, higher success rates than implants placed in the maxilla, with only a few exceptions noted. These data from human clinical experiences support the documented advantage of implants with a roughened surface in animal and in vitro experimentation and indicate that the magnitude of the advantage is significant for patient care. J Periodontol 1999;70:1523-1539.

KEY WORDS

Dental implants/therapeutic use; clinical trials; titanium; hydroxyapatite; comparison studies; dental implants/histology.

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Knowledge regarding endosseous dental implants has rapidly expanded over the last 30 years. The basis for this increase has been the recognition that implants can achieve predictably high clinical success rates. It is clear from the early studies of Brånemark et al.[1,2] and Schroeder et al.[3] that an understanding of the physiology of bone tissue led to the surgical placement of the implant under conditions that minimized heat production and which allowed for a healing phase where mobility was also minimized. Given these conditions, plus the use of a biocompatible material, clinicians and researchers quickly realized the potential of the endosseous implant in multiple restorative indications and in various areas of both jaws (see reference 4 for review). Most implants utilized have been made from titanium. However, a range of implant surface characteristics has been used, with each surface being evaluated by laboratory and animal experimentation and by human clinical experiences. Two of the best-documented surfaces are the machined titanium surfaces (typically considered a relatively smooth surface) and the machined surface that has been plasma sprayed with titanium (the TPS surface). This latter treatment was used to roughen and, therefore, increase the surface area of the implant, thus providing greater area for bone-to-implant contact. A third well-documented surface is hydroxyapatite. These surfaces, in addition to being rough and highly porous relative to the titanium surfaces, share some characteristics with the mineral content of bone tissue.[4]

Characterization of implant surfaces involves a variety of techniques including descriptive (histological and histomorphometric) studies and functional assays (biomechanical tests such as torque removal values and push out/pull out strength). Using these techniques, a large number of studies have been published on implants with different surface characteristics.[5-28] Most implant surfaces have been characterized and include descriptive histological or histomorphometric experiments examining the quality of the bone-implant interface and the amount of implant surface in contact with bone tissue. Other work has focused on functional studies determining the amount of force required to break the bone-to-implant contact or to remove the implant from the bone. In these studies, various animal models and bone types have been used including extraoral and intraoral bone. In general, a predominant finding has been that roughened implant surfaces have greater amounts of bone-to-implant contact than do smoother surfaces. In addition, greater forces are required to remove implants with a rougher surface compared to implants with a smoother surface.

One variable among the studies used to characterize implant surfaces has been the amount and location of cortical and cancellous bone in the model system used. Both types of bone are usually found in contact with the implant surface and contribute to the osseous integration of the implant. Furthermore, the experimental results in such studies can depend on how the analysis was performed. In some studies, for example, the animal model used contains predominantly one type of bone or the investigators analyzed only one area of the implant-bone contact, such as the "best consecutive 3 threads" (which in the majority of cases is cortical bone). For these reasons, when interpreting the results of studies characterizing implant surface characteristics, one must consider the type of analysis (in vitro, animal in vivo, human descriptive, biomechanical) and the type of bone tissue used to study the integration process (cortical, cancellous, woven, lamellar, oral, extraoral, long bone, etc).

It is well documented that different areas (i.e., anatomic locations) of the human oral cavity are composed of varying amounts of cortical and cancellous bone. Longitudinal human descriptive studies indicate that clinical success rates vary according to anatomic location.[4] For example, implants in the anterior mandible typically have some of the highest reported success rates, while the posterior maxilla has some of the lowest reported success rates. One reason given for the variability in success rates in various anatomic areas is the difference in quality of bone, such that areas with higher quality bone (i.e., cortical bone) have greater success rates compared to areas with reduced bone quality (cancellous bone). Bone quality is generally determined diagnostically with radiography or clinically by resistance during osteotomy preparation. Clinical strategies to increase success rates in areas of reduced bone quality include: 1) the use of longer or wider diameter implants; 2) the use of additional implants; and/or 3) the use of implants with a roughened surface. Each of these strategies is intended to provide for more bone-to-implant contact supporting the restoration.

The purpose of this report was to evaluate the number of patients treated and the number of implants used having various surface characteristics. For the purpose of this analysis, the number of implants placed with relatively smooth titanium surfaces is compared to the number of implants placed with rougher titanium surfaces and with hydroxyapatite-coated surfaces. Publications from prominent journals in implant dentistry published in English were reviewed and the number of maxilla and mandibles treated determined, as were the reported success rates and years of follow-up. The data are separated for various clinical indications including reports on edentulous cases; patients with removable overdentures; partially edentulous cases, single tooth implant restorations; and cases where multiple indications were treated. Finally, the success rates of implants with relatively smooth surfaces were compared by meta-analysis to the success rates of implants with roughened surfaces.

MATERIALS AND METHODS

The intent of this manuscript was to evaluate the published literature for reports that detailed the experience of investigators who have used endosseous dental implants in patients and which longitudinally assessed the implants using evaluation criteria. A critical review of the literature was conducted to determine the clinical efficacy of implants under various clinical indications. Synopsis tables from the studies were constructed, and the literature was divided into experiences with implants segregated by implant surface characteristics. Titanium implants were separated from hydroxyapatite-surfaced implants, and the titanium implants were further subdivided into implants with a relatively smooth surface from those that had a roughened surface. Articles published through 1997, written in English, and published in peer-reviewed journals were obtained through computer literature searches; manual searches through prominent journals in implant dentistry, periodontics, and prosthetics; and reference lists from other published papers.

Efforts were made to try to distinguish manuscripts published on identical populations of patients; however, this was not always possible depending on the information provided in the papers. Additionally, characterization of the surface of the implants was not always provided in the papers. It is recognized that different implant companies have surfaces that are similar but may not be identical. For example, all machined surfaces are not exactly the same (e.g., the Ra by profilometric analysis is different), nor are all titanium plasma-sprayed surfaces the same. For these reasons, implant surfaces that are machined in some fashion were categorized as relatively smooth titanium implants, while titanium implants that had treatment to roughen the surface (such as plasma spraying with titanium, blasting with titanium oxide, or sand blasting and/or acid treatment) were all categorized as roughened titanium-surfaced implants. Similarly, implants that are coated with hydroxyapatite can have various amounts of crystallinity, but for the purposes of this review, were all considered as hydroxyapatite-coated implants.

Each of the studies was evaluated for the number of patients treated and the number of mandibles and/or maxilla involved. In addition, the number of implants placed in each arch was determined as well as the length of follow-up and success rate according to criteria defined by the investigators. No attempt was made to critically analyze the success criteria in each study. A list of criteria used in studies is provided in Table 1. It is recognized that in some instances, some authors have actually considered implant survival (i.e., the implants are still in the mouth) though only criterion 11 Table 1 was listed. Contemporary literature emphasizes cumulative success rates based on life table analysis and it is recognized that this is the preferred analysis. However, since this report is a review of the literature, the criteria used in each paper are listed in the tables in reference to Table 1 so that the reader can evaluate each study in relation to the actual criteria used. Each of these studies was placed in a table depending on the clinical situation addressed. If a paper reported on patients with more than one indication treated, the study was grouped with similar papers in a separate table. The tables consisted of: 1) edentulous patients; 2) patients treated with removable overdentures; 3) partially edentulous patients; 4) patients with single tooth implant restorations; and 5) patients with multiple types of restorations and/or indications. Summary tables were constructed from each of these tables with regards to implant surface.

Meta-analysis was performed on the 5 categories of studies (Tables 2 through 6) using the Peto method.[29] As virtually all of the studies examined featured only one type of implant, studies within a category were combined to calculate the total number of successes and failures among rough surfaced implants as well as the respective totals for all implants with relatively smooth surfaces. With these totals, odds ratios comparing the success rates of rough versus smooth for each study category were computed. This process was also done separating the implants by location (maxilla and mandible) to determine if implant location affected the relative rates of success for implant types. In addition to the rough versus smooth comparisons, Table 6 features hydroxyapatite-coated implants that were compared to rough and smooth titanium implants separately. Finally, the relative success rates of implants placed

Table 1.

Criteria Used to Determine Success of Implant*

1. Less than 1 mm mobility in any direction
2. No radiolucency
3. Bone loss not greater than 1/3 of implant
4. Provide functional services for 5 years in 75% of cases
5. Absence of persistent and/or irreversible signs/symptoms such as pain, infection, neuropathies, paresthesia, violation of mandibular canal
6. Clinically immobile
7. No peri-implant radiolucency
8. Bone loss less than 0.2 mm annually after first year of service
9. 85% success after 5 years; 80% success after 10 years
10. Implant design allows restoration satisfactory to patient and dentist
11. Implant still in mouth
12. Absence of continuous marginal bone loss
13. Minimal marginal bone loss
14. Absence of persistent soft tissue complications
15. Surgical retrievability
16. Probing depth less than 4 to 5 mm, bone loss less than 4 mm
17. No mechanical failure (e.g., fracture)
18. Bone loss does not reach apical 1/3 of implant
19. Non-standardized radiographs demonstrate less than 50% of implant has bone loss

* 1 through 5 adapted from Schnitman and Shulman,[1] 5 through 9 from Albrektsson et al.,[2] 5 through 10 from Smith and Zarb,[3] and 11 through 19 from specific papers.

TABLE 1 REFERENCES

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2. 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.
3. Smith D, Zarb G. Criteria for success of osseointegrated endosseous implants. *J Prosthet Dent* 1989;62:567-572.

in the mandible and the maxilla were compared within implant type and category of studies.

RESULTS

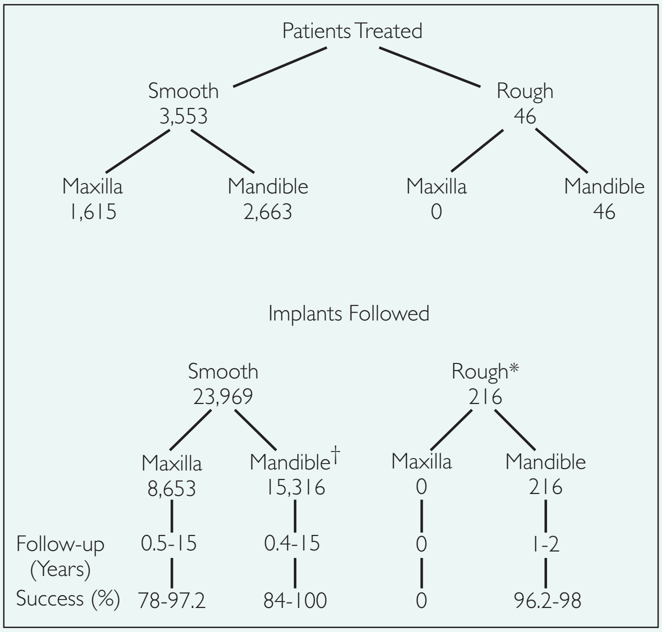
Different studies utilized various criteria to determine if an implant was successful (Table 1). This list is also a reference for the synopsis in the supplementary material so the reader can determine which criteria were utilized in each study (listed as "C" under "Type of Study"). Table 2 lists published studies that were reviewed on predominantly edentulous patients. Papers published on this indication alone reveal that relatively smooth implants have been reported on more frequently than implants with a roughened surface. The 3,553 patients treated with a smooth surfaced implant included 2,663 mandibles and 1,615 maxilla. There were 15,316 implants placed in the mandible and 8,653 placed in the maxilla for a total of 23,969 implants. The follow-up on these implants ranged from 0.4 to 15 years with a success rate of 78% to 100%. In reports using implants with a roughened surface and in predominantly edentulous patients alone, 46 patients were described, all treated in the mandible, using 216 implants. The follow-up period on these implants ranged from 1 to 2 years with a success rate of 96.2% to 98%.

Table 2* includes just 1 study, comprised of 216 rough-surfaced implants, which was compared to a combination of 13 studies with a total of 23,969 smooth implants. The resulting odds ratio of 1.91 (with 95% confidence interval (CI) of [1.20, 3.06]) indicated that rough surfaces had a superior success rate for all implants, regardless of location, compared to smooth surfaces (P <0.007). Because the one study using rough implants was limited to those placed in the mandible, no odds ratio was available for implants placed in the maxilla. When restricting smooth implants to those that were placed in the mandible, 12 studies were combined totaling 15,316 implants. The resulting odds ratio of 1.39 (95% CI = [0.76, 2.52]) was not significant (P >0.25), suggesting that restricting implant location to the mandible improved the success rate of smooth implants to the degree that smooth was no longer inferior to rough-surfaced implants. This finding is supported by the smooth implant location meta-analysis in Table 2, which indicated that placement in the mandible had superior success to placement in the maxilla (O.R. = 3.35, 95% CI = [3.05, 3.68], P<0.001).

* Tables illustrating the meta-analysis of the individual studies used to create the summary data shown in Tables 2 through 6 can be obtained by e-mailing Rita@perio.org or Julie@perio.org. Requests can also be mailed to the Managing Editor in Chicago.

Table 2.

Edentulous Patients



	Totals	
	23,969 Implants	216 Implants
Follow-up (years)	0.4-15	1-2
Success (%)	78-100	96.2-98

* Overall rough success > smooth (*P* <0.007).
† Smooth mandible > smooth maxilla (*P* <0.001).

TABLE 2 REFERENCES

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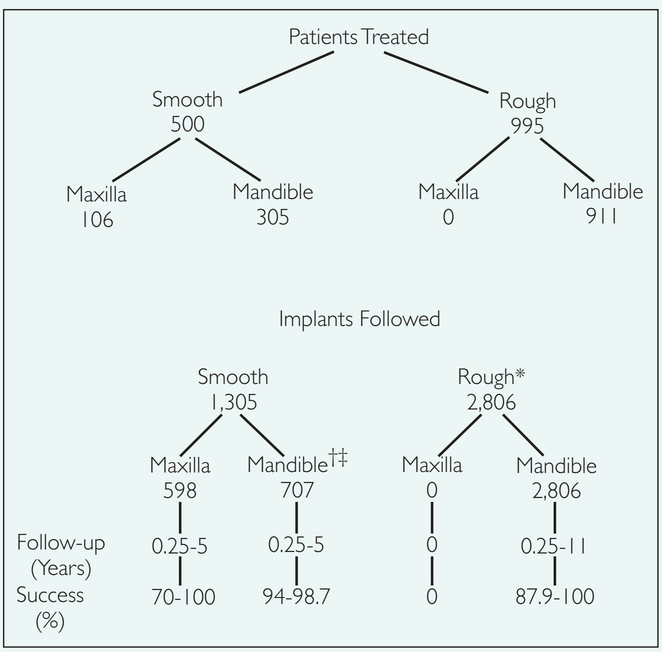
Table 3.

Patients Treated With Removable Overdentures



	Totals	
	1,305 Implants	2,806 Implants
Follow-up (years)	0.25-5	0.25-11
Success (%)	72.4-98.8	87.9-100

* Overall rough success > smooth (*P* <0.001).
† Smooth mandible > rough mandible (*P* <0.001).
‡ Smooth mandible > smooth maxilla (*P* <0.001).

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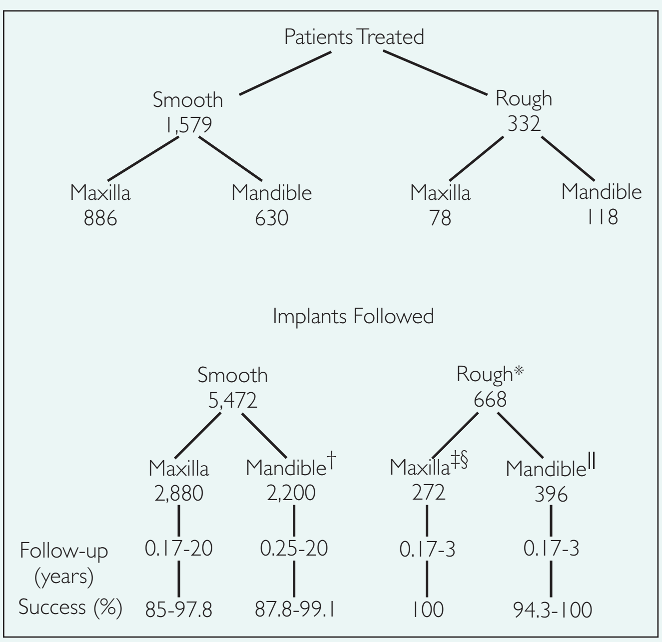
Table 4.

Partially Edentulous Patients



	Totals	
	5,472 Implants	668 Implants
Follow-up (years)	0.17-20	0.17-3
Success (%)	86.3-98.6	96.2-100

* Overall rough success > smooth (P<0.001).
† Smooth mandible > smooth maxilla (P= 0.055).
‡ Rough maxilla > rough mandible (P<0.042).
§ Rough maxilla > smooth maxilla (P<0.001).
|| Rough mandible > smooth mandible (P<0.01).

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Table 3 shows the results of studies treating patients with overdenture restorations. There were 500 patients treated with implants having a relatively smooth surface, and in these patients, 305 mandibles and 106 maxilla were treated. A total of 1,305 implants were used, 707 in the mandible and 598 in the maxilla. The overall follow-up period ranged from 0.25 to 5 years with a success rate of between 72.4% to 98.8%. Nine hundred ninety-five (995) patients were treated with implants that had a roughened surface and these included 911 mandibles. A total of 2,806 implants were placed, all in the mandible. The follow-up period for these implants ranged from 0.25 to 11 years with a success rate range of 87.9% to 100%.

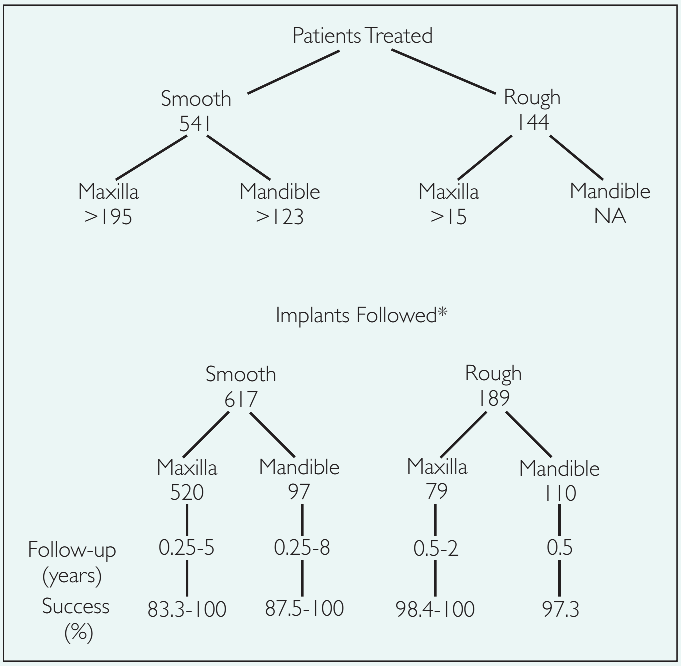
For Table 3, a combination of 8 studies totaling 2,806 rough implants was compared to a combination of 7 studies having 1,305 smooth implants. Rough was superior to smooth for all implants, regardless of location (O.R. = 1.64, 95% CI = [1.32, 2.04] P <0.001). However, as with Table 2, none of the rough implant studies in Table 3 had implants placed in the maxilla, so that an odds ratio for maxilla-positioned implants could not be calculated. When restricting smooth-surfaced implants to those that were placed in the mandible, 6 studies containing 707 smooth implants were combined. This improved the smooth success rate to the degree that smooth was superior to rough (O.R. = 0.46, 95% CI = [0.34, 0.63] P <0.001). Again, this finding is supported by the smooth implant location meta-analysis in Table 3, where mandibular implants were shown to have superior success compared to maxillary implants (O.R. = 6.49, 95% CI = [4.71, 8.95] P <0.001).

Partially edentulous patients treated with implants having a relatively smooth surface included 1,579 patients (Table 4). Of these, 630 mandibles and 886 maxilla were included. A total of 5,472 implants were placed, 2,200 in the mandible and 2,880 in the maxilla. The follow-up period ranged from 0.17 to 20 years with a success rate of 86.3% to 98.6%. Three hundred thirty-two (332) patients were reported with implants that had a roughened surface including 118 mandibles and 78 maxilla. A total of 668 implants were placed with 396 implants in the mandible and 272 implants in the maxilla. The follow-up period ranged from 0.17 to 3 years with a success rate of 96.2% to 100%. Three reports on implants with a roughened surface demonstrated a 100% success rate.

For Table 4, a combination of 7 studies with a total of 668 rough-surfaced implants was compared to a combination of 14 studies comprising 5,472 smooth implants. Rough was superior to smooth for all implants, regardless of location (O.R. = 2.64, 95% CI = [1.83, 3.81] P <0.001). Restricting the meta-analysis to maxilla-positioned implants, 6 rough (272 implants) and 13 smooth (2,880 implants) studies were combined, with the result that

Table 5.

Single Tooth



	Totals	
	617 Implants	189 Implants
Follow-up (years)	0.25-5	0.5-2
Success (%)	84-100	97.7-100

* Success rates for this table were not significantly different (*P* >0.24).

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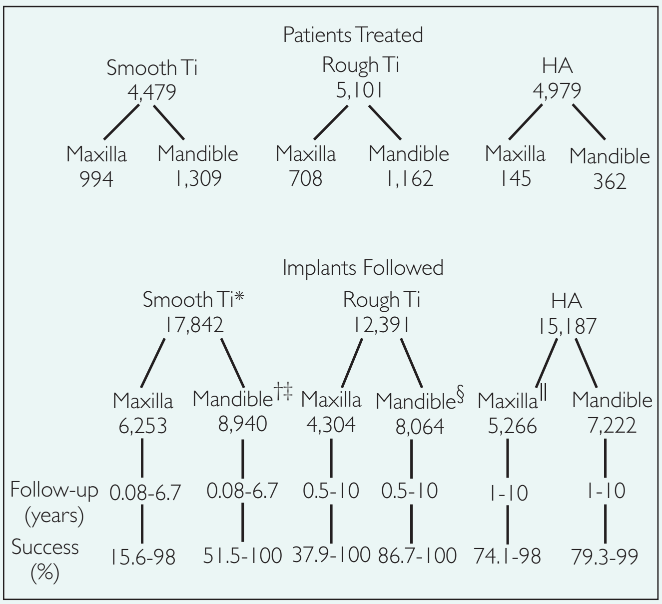
rough was superior to smooth (O.R. = 3.16, 95% CI = [1.79, 5.60] $P<0.001$). Consistent results were obtained when restricting the meta-analysis to implants placed in the mandible, for which 7 rough (396 implants) and 10 smooth (2,200 implants) studies were combined, with rough superior to smooth (O.R. = 2.10, 95% CI = [1.21, 3.67] $P<0.01$). The rough implant location meta-analysis in Table 4 indicated that the success rate for maxilla placement was slightly better than that for mandible placement (O.R. = 0.18, 95% CI = [0.04, 0.94] $P<0.042$), while for smooth implants the reverse was true, with the mandible having a marginally higher success rate (O.R. = 1.29, 95% CI = [0.99, 1.66] $P=0.055$).

Publications on single tooth implant restorations included 541 patients treated with implants having a relatively smooth surface (Table 5). Of these, more than 123 mandibles and 195 maxilla were included. Ninety-seven implants were placed in mandibles and 520 implants in the maxilla, giving a total of 617 relatively smooth implants placed. The overall follow-up ranged from 0.25 to 5 years with a success rate of

Table 6.

Multiple Indications



	Totals		
	17,842 Implants	12,391 Implants	15,187 Implants
Follow-up (years)	0.08-6.7	0.5-10	1-10
Success (%)	9.3-98.5	83.2-100	77.8-99.8

* Overall smooth success > HA > rough (P<0.001).
† Smooth mandible > rough mandible, HA mandible (P<0.001).
‡ Smooth mandible > smooth maxilla (P<0.001).
§ Rough mandible > rough maxilla (P<0.001).
‖ HA maxilla > smooth maxilla > rough maxilla (P<0.006).

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84% to 100%. One hundred forty-four (144) patients were treated with rough-surfaced implants. Of these, more than 15 maxilla were included with 79 implants. One hundred ten implants (110) were placed in mandibles, giving a total of 189 rough-surfaced implants reported. The follow-up period ranged from 0.5 to 2 years with a success rate range of 97.7% to 100%.

For Table 5, a combination of 2 studies totaling 189 rough implants was compared to a combination of 10 studies totaling 617 smooth implants. The success rates for rough and smooth implants were not significantly different (O.R. = 1.70, 95% CI = [0.70, 4.13] P >0.24). Two studies on rough-surfaced implants with a total of 79 maxillary-placed implants and 10 studies on smooth-surfaced implants with a total of 520 maxillary-placed implants were combined and compared. Again, the success rates for rough and smooth were not significantly different (O.R. = 1.99, 95% CI = [0.50, 7.94] P >0.33). One rough study with 110 mandibular implants was compared with the combination of 10 smooth studies with a total of 97 mandibular implants, with the result that rough was not significantly different from smooth (O.R. = 1.92, 95% CI = [0.47, 7.87] P >0.36). The rough and smooth implant location meta-analyses in Table 5 indicated no significant differences for success rates of the mandible and maxilla, with rough having an odds ratio of 0.50, 95% CI = [0.07, 3.67] (P >0.49) and smooth, an odds ratio of 0.58, 95% CI = [0.18, 1.86] (P >0.35).

Many publications included patients treated with multiple indications (Table 6). Four thousand four hundred seventy-nine (4,479) patients were treated with implants having relatively smooth surfaces; 1,309 mandibles and 994 maxilla were included. In these patients 17,842 implants were utilized with 8,940 in the mandible and 6,253 placed in the maxilla. These implants were followed from 0.08 to 6.7 years with a range in success from 9.3% to 98.5%. The lower success rate in most of these studies was much higher (around 85% to 87%), with only one study reporting a very low success range of 9.3% to 37.2%. The other 17 studies reported an overall range in success rate of 85.1% to 98.5%. For implants with a roughened surface, 5,101 patients were treated, with 1,162 mandibles and 708 maxilla included. In these patients, 12,391 implants were placed with 8,064 in the mandible and 4,304 in the maxilla. The overall follow-up period ranged from 0.5 to 10 years with a success rate of 83.2% to 100%. Four of the studies on implants with a roughened surface reported a success rate of 100%.

The publications reporting on the use of hydroxyapatite-coated (HA) implants included patients with various indications. Four thousand nine hundred seventy-nine (4,979) patients were reported and included 145 maxilla and 362 mandibles. In these patients, 15,187 implants were included with 5,266 implants placed in the maxilla and 7,222 placed in the mandible. The follow-up period ranged from 1 to 10 years with a success rate from 77.8% to 99.8%.

For Table 6, there were 14 studies containing 12,391 rough implants, 18 studies containing 17,842 smooth-surfaced implants, and 12 studies containing 15,187 hydroxyapatite-coated implants. These studies included multiple indications and, as such, had ideal and non-ideal cases mixed together. Smooth had superior success compared to rough (O.R. = 0.59, 95% CI = [0.66, 0.54] P <0.001) and HA (O.R. = 0.81, 95% CI = [0.73, 0.90] P <0.001), and hydroxyapatite was superior to rough (O.R. = 1.36, 95% CI = [1.23, 1.50], P <0.001) when all implants were considered. When restricting implants to those placed in the maxilla, there were 12 studies containing 4,259 rough implants (study 27 with 45 maxillary rough implants was dropped because the success rate in the maxilla was not specified), 15 studies containing 6,253 smooth implants, and 6 studies containing 5,009 HA implants (studies 7 and 33 with 25 and 232 maxillary implants, respectively, were dropped because the success rate was not reported). Hydroxyapatite had superior success compared to rough (O.R. = 2.83, 95% CI = [2.45, 3.26] P <0.001) and smooth (O.R. =1.25, 95% CI = [1.07, 1.47] P <0.006), while smooth was superior to rough (O.R. = 0.42, 95% CI = [0.37, 0.48] P <0.001). When restricting implants to those placed in the mandible, there were 13 studies containing 7,883 rough implants (study 27 with 181 mandibular rough implants was again dropped), 14 studies containing 8,940 smooth implants, and 7 studies containing 6,611 hydroxyapatite implants (studies 7 and 33 with 85 and 526 implants, respectively, were again dropped). Smooth had a better success rate than rough (O.R. = 0.52, 95% CI = [0.44, 0.61] P <0.001) and hydroxyapatite (O.R. = 0.49, 95% CI = [0.41, 0.58] P <0.001), while rough and hydroxyapatite were not significantly different (O.R. = 0.96, 95% CI = [0.82, 1.11] P >0.57). The rough (O.R. = 3.33, 95% CI = [2.90, 3.82] P <0.001) and smooth (O.R. = 2.62, 95% CI = 2.23, 3.08] P <0.001) implant location meta-analyses in Table 6 indicated that implants placed in the mandible had superior success rates compared to implants placed in the maxilla, while no significant differences were observed for hydroxyapatite implant location (O.R. = 1.01, 95% CI = [0.86, 1.19] P >0.89).

Using the Peto method,[29] a summary odds ratio using the rough-smooth odds ratios was calculated for each study category (Tables 2 through 6 for total implants and mandibular implants, and Tables 4 through 6 for maxillary implants). Summary results for total implants indicated smooth was superior to rough (O.R. = 0.8, 95% CI = [0.73, 0.87] P <0.001), as was the case for maxillary implants (O.R. = 0.47, 95% CI = [0.42, 0.54] P <0.001) and mandibular implants (O.R. = 0.59, 95% CI = [0.51, 0.67] P <0.001). Summary results were also calculated for the implant location meta-analyses using the odds ratios obtained for rough surfaces in Tables 4 through 6 and smooth surfaces in Tables 2 through 6 separately. The summary result for rough-surfaced implants (O.R. = 3.24, 95% CI = [2.82, 3.71] P <0.001) indicated that implant success was higher in the mandible, as was the result for smooth-surfaced implants (O.R. = 3.02, 95% CI = [2.80, 3.25] P <0.001).

DISCUSSION

A wide selection of endosseous dental implants from manufacturers is available to the clinician today. Included in these selections are implants with a relatively smooth surface as well as implants that have a roughened surface. The relatively smooth machined endosseous implant surface gained early popularity in the United States after its introduction in Canada marked by 3 publications describing a population of treated patients.[30-32] In these early studies reporting technique, edentulous mandibles were the predominant indication treated. Different implants were available to clinicians at this time and some had roughened surfaces. However, publications written in English focused on the relatively smooth implant surface and its use in edentulous patients (see Table 2). Different techniques have been used to create a rough (and enlarged) implant surface and, today, coated and non-coated implants are widely available using various techniques to create the roughened implant surface. Until a recent merger of 2 implant manufacturers, only 1 company continued to sell implants with only a relatively smooth surface. Now, virtually every dental implant manufacturer sells implants that feature some form of roughened surface.

The data are overwhelming that implants with a roughened surface provide for a greater bone-to-implant contact at the histological level compared to implants with a smoother surface. Additionally, functional tests of the implants such as torque removal values and studies measuring push out or pull out strengths from bone also demonstrated that implants with a roughened surface have enhanced contact with bone compared to implants with a more smooth surface.[5-28] A classic study describing bone-to-implant contact around endosseous implants with different surfaces was published in 1991 by Buser et al.[5] In this study, 72 similarly shaped cylindrical implants were placed in miniature pigs. Six different surfaces were compared, 5 of which were titanium and the sixth a hydroxyapatite-coated implant. The results indicated that surfaces with increasing roughness had greater bone-to-implant contact. Electropolished and medium grit-blasted implant surfaces had the lowest amount of bone-to-implant contact. Large-grit sandblasted and titanium plasma-sprayed implants had greater bone-to-implant contact. The titanium implant with the highest bone-to-implant contact was created by large-grit sandblasting and acid attack. This surface gave similar bone-to-implant contact, as did implants that had been coated with hydroxyapatite. A histological finding with the hydroxyapatite-coated implants was a localized resorption of the hydroxyapatite surface coating. Thus, titanium implants with a roughened surface created by sandblasting, sandblasting and acid attack, or titanium plasma-spraying demonstrated greater bone-to-implant contact than did titanium implants with smoother surfaces. The authors concluded, "The extent of bone-implant interface is positively correlated with an increasing roughness of the implant surface.[5]"

Many other studies support the fact that implants with a rough surface have greater bone-to-implant contact than implants with a more smooth surface.[6-28] These publications include an early study by Thomas and Cook[20] which demonstrated that of the parameters evaluated, only surface texture influenced implant integration. In reviewing the literature for this report, it became obvious that not all publications described the surface characteristics of the implants being tested. It should also be noted that even if similar techniques are utilized to obtain a roughened surface, the conditions of the treatment could have an effect. For example, if an acid is used, the concentration of the acid, the time of exposure, and the temperature of the acid bath can all influence the resulting surface characteristics. For these reasons, adequate characterization of the implant surface should be provided in publications. An example of differences between implants with 2 roughened surfaces has recently been published.[33] In this case, 1 implant surface was created directly by acid attack while the other was created by large-grit blasting followed by acid attack. Although this study compared 2 implants which had different design features other than the different rough surfaces, another recent study has confirmed that identically designed implants with roughened titanium surfaces have greater removal torque values than titanium implants with more smooth surfaces.[34] These studies have confirmed the findings of in vitro studies [35-39] and other in vivo implant studies noted above on rough-surfaced titanium compared to smoother titanium surfaces.

The above discussion indicates clearly that implants with a roughened surface have significant advantages over implants with smoother surfaces in regards to osseointegration and biomechanical (functional) assays. The clinical question, however, is whether this difference will be reflected in clinical success rates with patients. This is, admittedly, a difficult question due to the nature of assaying human clinical data. For instance, the publications reviewed in this paper are longitudinal descriptions of implants in patients in specific indications. As such, using clinical evaluation criteria such as lack of detectable clinical mobility, absence of pain and irreversible infection, crestal bone loss to a certain degree, etc., may not be precise enough to detect differences due to implant surface characteristics. However, a difference due to surface characteristics may become evident if an individual implant is subjected to forces or stresses that are close to the point where the bone-to-implant contact may fail. Clinical situations where this is more likely to be found include the posterior areas of the mouth, such as when a single implant is used to replace a single molar; in the posterior mandible or maxilla where the amount of cortical bone is diminished and where forces are greater; and/or in situations where the crown-to-implant ratio is high. In these cases, use of an implant that provides for greater amounts of bone-to-implant contact, such as titanium implants with a roughened surface, would appear to be prudent. An experimental situation which evaluates the strength of the bone-to-implant contact is the torque removal value where failure of the bone-to-implant contact is actually determined. If an implant is subjected to a certain level of force, when will it become disengaged from the bone; i.e., when is osseointegration lost? This is relevant when determining how much osseointegration is required to support an implant under function. Clearly, the implant that has the highest bone-to-implant contact and that will resist greater forces is preferred to the implant that has less bone-to-implant contact and cannot resist loss of integration at lower forces.

The available human clinical data to evaluate the use of implants are currently published as descriptive longitudinal experiences for specific clinical indications. For this reason, the present report has analyzed the data in regards to implants with relatively smooth surfaces compared to implants with rougher surfaces. Two considerations limit the ability to detect differences due to surface characteristics. The first is that many of the implants were placed in areas with high bone quality and under ideal conditions. These include situations where the implants were placed in predominantly cortical bone and placed with bicortical stabilization, with restorations that provide cross arch splinting and, which oppose denture teeth. Under these conditions, it would be unlikely to detect differences in implants due to surface characteristics. The other limiting factor to detecting clinical differences between implants with relatively smooth surfaces compared to rough-surfaced implants is the use of the criteria used to determine implant success (Table 1). These criteria do not reflect the amount of force applied to the implant nor reflect what forces the implant could resist. In addition, these criteria provide little information about the tissue integration (soft or hard tissue) of the implant nor the amount or degree of inflammation. Furthermore, even using the success criteria listed, in general, there are very few implants that fail. Thus, in order to detect differences between implants with different surface characteristics, large numbers of implants placed under similar clinical conditions would be required. The meta-analysis presented in this report is, therefore, one approach to addressing this latter problem given the available published clinical data.

The data presented in this report indicate that in the case of predominantly edentulous patients, the vast majority of reported implants placed had relatively smooth surfaces. Additionally, the implants and restorations used were, in general, placed under ideal conditions. This was likely due, as noted above, to the fact that the introduction of currently used submerged endosseous implants in North America first

Table 7.

Success Rate Summary

	Table 2 Edentulous	Table 3 Overdentures	Table 4 Partially Edentulous	Table 5 Single Tooth	Table 6 Multiple Indications	Overall Odds Ratio*
All implants, all locations	R>S	R>S	R>S	R=S	S>HA>R	S>R
Location restriction Maxilla			R>S	R=S	HA>S>R	S>R
Location restriction Mandible	R=S	S>R	R>S	R=S	S>R>HA	S>R
Location meta-analysis Rough			Max>Mand	Mand=Max	Mand>Max	Mand>Max
Location meta-analysis Smooth	Mand>Max	Mand>Max	Mand>Max	Mand=Max	Mand>Max	Mand>Max
Location meta-analysis HA					Mand=Max	

R=rough; S=smooth; HA=hydroxyapatite; Mand=mandible; Max=maxilla.
* Overall odds ratio using table odds ratios.

utilized implants with a machined surface. The meta-analysis revealed that the success rate of the rough-surfaced implants was significantly greater than the success rate for the implants with smoother surfaces (Table 7). If the smooth implants placed in the mandible were compared to the rough-surfaced implants (which were only placed in the mandible), the success rates were comparable between the rough and smooth implants. This result was due to the significantly enhanced success rate of implants placed in the mandible compared to the success rate in the maxilla for the smooth-surfaced implants. Similar results were obtained when edentulous arches were treated with overdenture restorations. Again, the success rate of rough-surfaced implants was significantly higher than the success rate of implants with smoother surfaces. Additionally, the smooth implant success rate was greater in the mandible than in the maxilla; when compared to the rough-surfaced implant success rate in the mandible only, this was significantly greater.

As implant indications broadened to include partially edentulous patients, endosseous implants were used in the posterior mandible and the maxilla (under less ideal conditions of both bone quality and occlusion). Under these conditions, implants with a roughened surface had significantly higher success rates than implants placed with smoother surfaces. Furthermore, if one compares rough and smooth implants placed in either the maxilla or mandible, the rough-surfaced implant success rate was significantly greater than the smooth-surfaced implants in either arch. Similar to the implants placed in edentulous arches, the success rate of smooth implants was greater in the mandible than in the maxilla. Interestingly, however, in areas of typically lower bone quality, the maxillary arch success rate for rough-surfaced implants was significantly greater than the success rate in the mandible for these implants. This finding supports the discussion above that differences in success rates due to implant surface characteristics are more likely to be found under conditions which are less ideal compared to more ideal situations.

No significant differences were found in success rates between rough and smooth implants when the implants were used to support single tooth restorations. This was true when either all implants were evaluated or when implants were considered only in the maxillary or mandibular arch. Additionally, if only rough or smooth implants were evaluated between arches, the success rate in either case was similar in the mandible and in the maxilla. The reason for the similar success rates between the rough- and smooth-surfaced implants used for single tooth replacements is not known but may be related to the fact that in most instances, adjacent natural teeth were present with the result that less alveolar resorption may have occurred compared to more extended edentulous area remodeling. Furthermore, the adjacent teeth may provide more occlusal “protection” in single tooth replacements compared to when larger amounts of the dentition are supported by implants and fewer natural teeth are present.

When multiple implant indications and varying restorations are combined, implants placed under more ideal conditions are mixed with implants placed under less ideal conditions. As noted above, differences due to implant surface characteristics under these conditions are more likely difficult to discern. The meta-analysis indicated that the success rates, when evaluating publications on multiple indications, were the greatest for smooth implants, followed by hydroxyapatite-coated implants, followed by rough-surfaced implants. If only the maxillary arch is examined, hydroxyapatite-coated implants had higher success rates than did smooth surfaces, which were greater than the rates for rough-surfaced implants. In the mandible, the success rates were highest for smooth implants followed by rough-surfaced implants and then hydroxyapatite-coated implants. For both rough and smooth surfaced implants, using studies reporting multiple indications the success rate was always significantly greater in the mandible compared to the maxilla. For hydroxyapatite-coated implants no difference was found between the maxilla and the mandible. Furthermore, if an overall odds ratio was calculated (based upon individual table odds ratios), smooth-surfaced implants had higher success rates than rough-surfaced implants when either all implants were considered or only implants in the maxilla or mandible. Again, however, for both rough- and smooth-surfaced implants, those implants placed in the mandible had significantly higher success rates than those placed in the maxilla.

In summary, human clinical studies evaluating implants placed in patients and followed longitudinally indicate that predictably high success rates can be achieved for rough- and smooth-surfaced titanium implants and for hydroxyapatite-coated implants. When studies are grouped such that specific indications are clustered, rough-surfaced implants had significantly higher success rates compared to implants with more smooth surfaces, except in the case of single tooth replacements where the success rates were comparable. A further prominent finding in this analysis was that implants placed in the mandible, when evaluated in specific indications or when evaluated in studies consisting of multiple indications, had significantly higher success rates than implants placed in the maxilla. Exceptions to this were the cases of rough and smooth implants for single tooth implant restoration and the cases reporting hydroxyapatite-coated implants where the success rate in the maxilla and mandible were comparable. Lastly, in partially edentulous patients, rough-surfaced titanium implants had a significantly higher success rate in the maxillary arch compared to implants placed in the mandibular arch.

Thus, the findings in this study evaluating published human clinical trials reveal that the advantage of a roughened titanium implant surface, demonstrated in animal and in vitro experiments, can also be demonstrated in clinical cases when studies are compared with specific indications or patient groups. The use of meta-analysis, by definition, requires many assumptions (for instance, in this study, length of follow-up was provided but not used in the odds ratio calculations), but the analysis does provide for a comparison to be made between published studies. Another limitation is the fact that an equal number of studies, implants or patients are not available for comparison between rough, smooth and hydroxyapatite implants; however, the meta-analysis using odds ratios adjusts for any inequalities in sample size. These results, taken together, suggest to the clinician that under specific indications, based on the published literature, implants in general with rough surfaces offer significant advantages over implants with more smooth surfaces and that implants placed in the mandible generally have significantly higher success rates than implants placed in the maxilla regardless of the implant surface.

ACKNOWLEDGMENTS

The author would like to gratefully acknowledge the excellent help and encouragement of many individuals in putting together this manuscript. Some of these individuals include Karen Lucas, Karen Holt, Pat Navarro, Josie De La Cruz, and Thomas Oates. The author would like to particularly thank John Schoolfield, statistician, for his support and work on the statistical analysis.

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Accepted for publication March 5, 1999.