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Torque removal force for osseointegrated implants – two experimental studies

J. F. LOWNIE, PH.D., F.C.M.F.O.S. (S.A.)
P. A. BETTS, M.DENT. (M.F.O.S.), F.C.M.F.O.S. (S.A.).
R. S. BRYANT, M.DENT. (M.F.O.S.), F.C.M.O.F.S. (S.A.).
P. CLEATON-JONES, D.SC. (DENT), F.C.D. (S.A.).

Divisions of Maxillofacial and Oral Surgery, and Experimental Odontology, University of the Witwatersrand, Johannesburg

Summary

Objective. To introduce a rabbit-based model for testing the torque removal force (TRF) of implants and to compare the TRF of a series of titanium implants.

Methods. Two experiments were performed at the University of the Witwatersrand. In the first, a Swedish- (SSM-N) or a South African-manufactured (SSM-S) implant was implanted into the tibiae of 12 rabbits and the TRF measured at 1, 3 and 6 months. In the second experiment, the TRF of 4 South African-manufactured titanium implants in the tibia or femur of 32 rabbits were compared at 3 and 6 weeks. The implants were: 1 threaded machined (SSM-S), and 3 surface-enhanced – 1 threaded (SLA), 1 threaded tapered (MTT) and 1 pitted (RI).

Results. In experiment 1, TRF increased significantly with time ($p<0.05$) but there was no significant difference between TRF for the South African and Swedish machined-surface implant types. In experiment 2, the TRF of the MTT implant was significantly greater ($p<0.0001$) than the other 3 types, which did not differ significantly from each other. Time had no significant effect.

Conclusion. In an internationally used rabbit-based model, South African and Swedish machined-surface titanium implants were equivalent; surface-enhanced implants produced higher TRF, and a tapered implant showed the highest TRF.

Since Brånemark *et al.*'s 1969 description of osseointegration as the direct contact between bone and titanium implants, the use of these implants has changed many aspects of surgery including individual tooth implants and support for intra-oral and extra-oral prostheses.[1] A fundamental point made by these authors is that if an implant is to be used clinically, it should first be studied using an experimental animal rather than by trial and error in humans.[1]

An animal in which torque removal and histological studies of bone response to implant materials has been tested for many years, is the rabbit.[2,3] Initial experimental research was on machined-surface implants over periods up to 12 months but, more recently, machined surfaces were substituted by surface-enhanced implants that produced earlier stability so that experiment times were shortened to 6 weeks.[3]

This article describes two experimental studies. The first dealt with the introduction into the University of the Witwatersrand's Division of Maxillofacial and Oral Surgery of the experimental testing method in rabbits used in Sweden, combined with a comparison of torque removal forces (TRFs) of the then available Swedish Brånemark machined-surface implant with the newly introduced South African-manufactured equivalent.[4] In the second experiment, the established rabbit model was used to compare TRFs of some surface-enhanced implants available in South Africa.[5]

Methods

Permission for the experiments was granted by the Animal Ethics Steering Committee of the University, which was carried out by the University's Central Animal Service.

Experiment 1 – establishment of the animal model

Two commercial machined-surface implants were studied. One was the Brånemark System Implant (Nobelpharma AB, Goteborg, Sweden; termed SSM-N); the other was a South African equivalent (Southern Implants, Irene, South Africa; termed SSM-S). Both were of commercially pure titanium machined to produce a threaded implant without surface enhancement. Their dimensions were identical: 7 mm long × 3.75 mm in diameter – a size to fit the proximal end of a rabbit tibia.

Twelve adult male lop-eared rabbits of the same age, ranging in weight from 2.5 kg to 3.0 kg were anaesthetised with intramuscular xylazine (Rompin 8 mg/kg, Centaur Laboratories, Isando, South Africa) and ketamine hydrochloride (Ketalar 25 mg/kg, Centaur Laboratories, Isando, South Africa). They breathed oxygen by face mask during surgery. Under aseptic conditions in the operating theatre of the CAS, each rabbit had 1 implant of the same type placed in the left and right proximal tibias using standard implant placement methods, including a cover screw, to produce replicates within each animal. For postoperative pain, intramuscular buprenorphine hydrochloride (Temgesic 0.15 mg/kg, Shering-Plough, Sandton, South Africa) was available at the discretion of the consultant veterinarian. No antibiotics were administered.

Four rabbits, 2 with each implant type, were humanely euthanased at 1, 3 and 6 months after surgery with intravenous pentobarbitone (Euthanase®, Centaur Laboratories, Isando, South Africa). The cover screw of each implant was exposed and removed, after which a torque gauge (Model 15 BTG-N, Johnichi, Tokyo, Japan) was attached using a purpose-made connector that screwed into the internal thread of the implant and had a triangular head to fit the jaw of the torque gauge. The leg of the rabbit was stabilised during measurement by strapping two vaculitre bottles alongside. The TRF to loosen each implant was recorded in N.cm (Newton centimetres).

Statistical analysis was carried out by using BMDP® software (Statistical Solutions, Cork, Ireland) with the experiment as a between-animals factorial design with two main effects: implant type (SSM-N, SSM-S) and time (1, 3, 6 months). Scheffe's pair-wise comparison was used for the main effect of time.

Experiment 2 – comparison of surface types

In this experiment, 4 implants of 7 mm length with different surfaces were compared; all were manufactured by Southern Implants (Irene, South Africa). The implants were:

- Control – the smooth-surface, threaded SSM-S used in experiment 1
- SLA – a threaded implant identical to the SSM-S but with the surface sand-blasted with large-particle aluminium tri-oxide particles, followed by acid etching
- MTT – a micro-threaded tapered implant (from 5.0 mm at the coronal end to 3.75 mm at the apex) with the surface enhanced as for the SLA
- Ripamonti – an implant with concavities instead of a thread, and the same surface enhancement as the SLA implant.

The experimental animals were adult New Zealand White rabbits of the same age, and 3.3 - 4.8 kg in weight; the surgical technique and euthanasia was identical to experiment 1. The experimental design was for random allocation of two implant types, one per proximal tibia in 32 rabbits with half the rabbits scheduled for euthanasia at 3 weeks and the other half at 6 weeks. After beginning the study, this design had to be altered because the tapered MTT implants produced fractures in 4 rabbits (which were euthanased). Placement of the MTT implants was changed to the distal femur, where only 1 fracture occurred. Rabbits were replaced and where possible so were implants, except for the MTT, of which no further examples were available. The replacements affected final numbers of rabbits and implants (Table II). TRF was measured in the same way as in experiment 1.

Statistical analysis was carried out with SAS for Windows® (SAS Institute Inc, Cary, NC, USA) using the general linear models test with TRF as the dependent variable and implant type, rabbit, side, sex and postoperative time as independent variables. A pair-wise comparison of TRF used Tukey's standardised range test.

Results

Experiment 1 – establishment of the animal model

The TRF results are listed in Table I. One torque value is missing at 6 months because the hexagonal portion of a Brånemark implant stripped during removal, making measurement impossible. There was an increase in TRF with time, the increase in mean TRF being greater from 1 to 3 months than from 3 to 6 months. The range of TRF at 6 months was higher than at the earlier assessment points, emphasised by the large standard deviations at 6 months. TRFs in N.cm at 6 months were 32, 90 and 110 for the SSM-N implant, and 19, 86, 98 and 110 for the SSM-S.

TABLE I. TORQUE REMOVAL FORCE (N.CM) FOR TWO MACHINED-SURFACE IMPLANTS AT 3 POSTOPERATIVE TIME INTERVALS

Months		SSM-N	SSM-S
1	*N*	4	4
	Mean	27.5	38.5
	SD	13.2	15.2
	Range	18 - 46	23 - 52
3	*N*	4	4
	Mean	72.5	68.3
	SD	10.8	11.8
	Range	58 - 84	52 - 78
6	*N*	3	4
	Mean	80.7	78.3
	SD	44.7	40.7
	Range	32 - 120	19 - 110

Statistical analysis showed the overall effect of time to be significant ($p<0.05$) as were the pooled values at 1 month compared with the other two periods ($p<0.05$). There was no significant difference between the pooled values for 3 and 6 months. The point estimate given by the mean torque ratio of SSM-S to SSM-N was 61.7/58.4, suggesting a possible 5.7% advantage of the SSM-S implant, which is a narrow and inconclusive margin. The implants are at least equivalent.

Experiment 2 – comparison of surface types

Table II lists TRF for the 4 test implants at the two time intervals. The variation in sample numbers between the experimental groups is due to the redesign of the experiment described in the Methods section above. The highest TRF at both time intervals was for the MTT implant, followed by the Ripamonti type. General linear models analysis showed a highly significant effect of implant type ($p<0.0001$) but no significant effects of postoperative time, rabbit sex or operative side. Tukey's standardised range test showed that MTT implants had significantly higher TRF than each of the other 3 implant types. In contrast, the TRF of the remaining 3 implant types did not differ significantly between each other.

Discussion

Principal findings

The outcomes of the of the first experiment were similar to the same type of experiment performed on rabbits in Sweden,[2,3] indicating reproducibility of method. The finding in the second experiment (that surface-enhanced implants have higher TRF than machined surfaces) confirms the observations of Knobloch *et al.*[6]

TABLE II. TORQUE REMOVAL FORCE (N.CM) FOR 1 MACHINED-SURFACE AND 3 SURFACE-ENHANCED IMPLANTS AT 2 POSTOPERATIVE TIME INTERVALS

Weeks		SSM-S	SLA	MTT	Ripamonti
3	*N*	8	9	5	10
	Mean	35.8	32.4	56.0	37.7
	SD	18.2	11.1	6.2	16.3
	Range	20- 56	20 - 50	48 - 64	20 - 54
6	*N*	10	8	4	6
	Mean	27.6	33.8	62.5	46.5
	SD	7.4	16.7	9.6	16.7
	Range	20 - 46	20 - 70	50 - 70	30 - 70

Strengths and weaknesses of the studies

The current experiments have confirmed that the rabbit is a suitable experimental model, and that healing response in this species is comparable with that in dogs[6] and, based on personal experience, with that in humans. As far as economics are concerned, a rabbit-based model is cost-effective. A potential weakness shown in the second study is that bone thickness at the experimental implant site must be carefully considered, shown by the number of fractures when the tapered MTT implant was placed in the tibia instead of the more robust femur.

Are the South African-manufactured implants used in our experimental studies satisfactory? Studies in Sweden by Albrektsson, and by Wennerberg (unpublished results, International Congress of the Academy of Prosthodontics held in Sandton on 5 February 2007) show that, although fixture designs have many surface modifications, evidence supporting the success of many of them is scanty. However, bone and surface studies by these researchers using South African implants (Southern Implants, Irene, South Africa) indicate that the implants have an enhanced surface after sandblasting with aluminium oxide, which aids rapid integration. Our experimental results support this finding.

Meaning of the studies

The first experiment indicates that similarly manufactured implants in two countries (South Africa and Sweden) produce similar TRF values.

It is clear from the results in the present study and those reported by other researchers that surface-enhanced implants produce higher TRF values than those with machined surfaces alone.[2,3,6] The explanation for this is not yet clear although, from examining human osteoblast proliferation and gene expression *in vitro*, Marinucci *et al.*[7] found that a rougher surface, macro-sandblasted titanium favoured osteoblast differentiation, compared with machined titanium implants.

Since shorter implants, of the 7 mm length used in our experimental studies, are sometimes needed in atrophic mandibles and maxillae, the use of surface-coated screw-type implants is essential to present a large surface area for bone to integrate with. If TRF for these implants is sufficient to avoid costly accompanying bone grafts, this would be most favourable. das Neves *et al.*,[8] in a longitudinal study of 16 344 implants placed over 24 years, found that implants with a length of 7 mm had a failure rate of 9.7% compared with 6.3% for 10 mm implants. This small difference in failure rate supports the view that 7 mm implants may be acceptable.

Future research

It is clear from clinical practice that titanium implants are an accepted treatment option. We believe that three research directions are likely in future:

- The search for the 'ultimate' implant surface enhancement will continue.
- Implant use will extend to severely resorbed jaws, using short implants with or without bone grafting.[8]
- The examination of factors modifying implant success, such as smoking, will be extended.[9]

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