Research article

Anchorage of machined and TPS-coated dental implants of various lengths: An *in vivo* study in the dog maxilla

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Abstract

Background and objectives. The use of short implants is nowadays frequent in daily practice. The objective of this experimental study was to test the correlation between extremely different implant surfaces and the anchorage of short implants.

Materials and Methods. The anchorage of machined-surface and titanium-plasma sprayed (TPS) implants of various lengths was investigated in the dog maxilla. Machined-surface fixtures, 7 and 10 mm long, and TPS implants, 6 and 10 mm long, were reverse-torqued after 3 months of healing.

Results. Failure mode varied with the implant system used. For TPS implants, implant loosening coincided with the peak reverse-torque. The mean was 55.13 and 90.14 Ncm for the 6 mm and 10 mm long implants, respectively; the difference was statistically significant. For machined-surface implants, 2 torque values were measured, a mobilization and peak torque. Mobilization torque for the 7 and 10 mm fixtures was 19.50 and 22.12 Ncm, respectively. Peak torque was 29.63 and 39.25 Ncm, respectively; all differences were not statistically significant. The 6 mm TPS implants were more firmly anchored than the 7 and 10 mm machined-surface fixtures. The torque data measured in the maxilla were significantly lower than the data in the mandible, by half approximately.

Discussion and Conclusion. In this experiment, parameters that influenced implant anchorage were: 1) the jaw bone quality (mandible vs. maxilla), 2) the implant surface and design, 3) implant length for TPS-coated implants. The present data suggest that treatment planning in terms of implant length selection and appropriate healing periods is implant system specific.

Keywords. Dental implants, materials testing, maxilla, titanium.

1. Introduction

Implant therapy, for partially and fully edentulous patients, is widely accepted as a safe and highly reproducible treatment. In the posterior region of the maxilla, where the sinus often limits the use of long implants, the need of complex surgical interventions prior to implant placement has been justified by the old paradigm that longer implants guarantee better success rates **[1]**. This paradigm is largely debated due to the technological evolutions of the implant systems, as the recent improvements of implant designs and surfaces reduced significantly the influence of the length parameter. However, it remains a significant parameter, particularly for complex treatments using sinus-lift and immediate implantation in the severely resorbed maxilla **[2,3]**.

Machined-surface and Titanium Plasma-Spayed (TPS) implants are almost no more used nowadays, as these 2 technologies are sometimes considered obsolete in dental impant surface science **[4]**. However from a scientific standpoint, these 2 technologies remain very interesting as they represent the 2 extremes of implant surface technologies: the machined-surface was the smoother surface available at the microscale (with no official chemical modifications or engineered nanostructures), what made this implant an important basis of comparison for the development of new surface treatments **[4]**. On the other side, the TPS surface is often considered as the rougher implant surface (at the microscale) that was used in modern implantology, what made this implant an important tool for the research of osseointegration through bone/implant surface biomechanical interlocking **[4]**. These 2 surfaces represent 2 different concepts and approach of osseointegration **[5]**. As they are so extremely different, they are particularly useful in comparative studies to investigate some specific mechanisms.

The machined-surface fixtures and the TPS implant systems have been extensively documented clinically over the years. Users of machined-surface implant systems repeatedly reported that short implants ≤10 mm were at a higher failure risk than longer ones, particularly in the maxilla **[6]**. In contrast, users of the TPS-coated implant system observed similar survival rates for both shorter (≤10 mm) and longer implants, whatever the location **[7]**.

In this study, we investigated the different implant bone anchorage of machined-surface and TPS-coated implants in a dog maxilla model depending on their short or standard lengths. For each implant system, the anchorage of implants of 2 different lengths was evaluated using the removal torque test after 3 months of healing in the dog maxilla, to complete our previous investigations in the mandible **[8]**.

2. Materials and methods

2.1. Implant design and surfaces

Implants selected for the study were commercially available standard implants. Sixteen Brånemark implants of diameter 3.75 mm (Nobelbiocare AG, Göteborg, Sweden) were distributed into eight 7 mm long and eight 10 mm long implants **(Figure 1)**. Sixteen solid screw Straumann implants (Straumann AG, Basel, Switzerland) of diameter 4.1 mm were distributed into eight 6 mm long and eight 10 mm long implants **(Figure 1)**. Surface state of the Brånemark fixtures is machined **(Figure 2a)** whereas surface state of the Straumann implants is roughened by titanium plasma-spraying **(Figure 2b)**.

These surfaces and implant systems were widely tested and characterized in the literature. Following the recently defined classification **[5,9]**, the machined-surface Brånemark fixtures are smooth at the microscale and smooth at the nanoscale. Straumann implants are maximally rough at the microscale and smooth at the nanoscale. Both surface technologies do not display chemical modifications, even if some minor contaminants may sometimes be found. The differences between the 2 surfaces are therefore only their microtopography, as previously explained. Moreover, the 2 implants systems do not have exactly the same screw design, and this bias is discussed further.

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Figure 1. Commercially available Brånemark and Straumann implants used in this study. From left to right, 7 mm Brånemark, 6 mm ITI, 10 mm Brånemark and 10 mm Straumann implants.

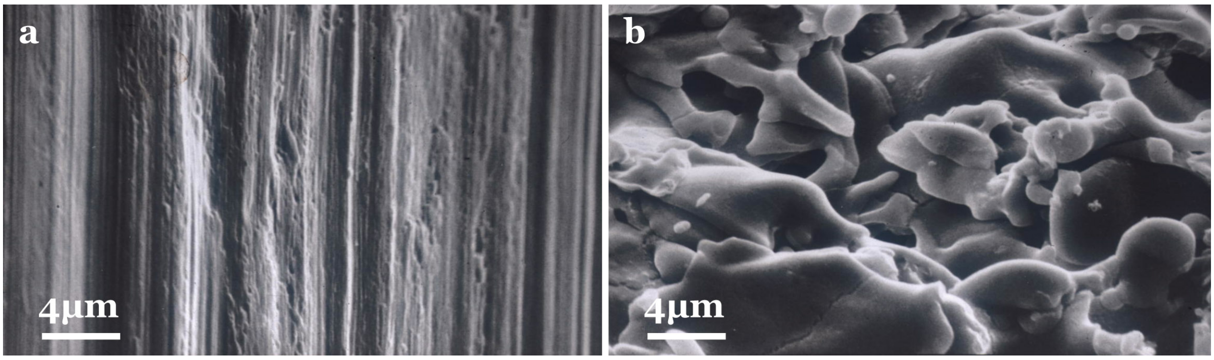

Figure 2. Scanning electron microscopy micrographs of the implants surfaces.
(a) Brånemark fixture, the surface feature corresponds to the machining grooves (x 3000).
(b) Straumann implant, the surface is roughened by titanium plasma-spraying (x 3000).

2.2. Experimental procedure

After protocol approval by the local institutional animal ethics committee, the animal study was conducted in an accredited experimental surgery center (Biomatech-Namsa, Chasse-sur-Rhône, France). Four Anglo-French adult male dogs (14-17 months old), weighing 30-31 kg were selected for this study. This breed can accommodate 10 mm long implants without encroaching the vital structures of the mandibular canal and the maxillary sinus **[8]**, whereas in beagle dogs the available bone height is limited to 6-8 mm. The surgical protocol was described previously **[8]**. Briefly, bilateral extractions of the PM1-PM4 premolars and the M1-M2 molars were performed in the maxilla. After 3 months of healing, 4 Brånemark fixtures (2 x 7 mm long and 2 x 10 mm long) were inserted in one side of the posterior maxilla and 4 Straumann implants (2 x 6 mm long and 2 x 10 mm long) in the other side. Particular care was taken to get the entire implant length in contact with surrounding bone. Bone height was evaluated during the drilling sequence, and when bone height was insufficient to host the entire implant, another site was prepared. For this reason dog 3 hosted 3 implants of 6 mm instead of 2 whilst dog 4 received 3 implants of 10 mm. **Table 1** shows implant distribution in each hemi-maxilla.

Implant placement was performed following the manufacturers' recommendations; Brånemark fixtures were left to heal in a submerged way according to the two-stage surgical procedure **[10]**. Straumann implants were inserted following the one-stage transmucosal

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technique **[11]**. During the 3-months healing period, the dogs were left on a soft diet; Straumann implants were professionally cleaned 3 times a week.

	Machined-surface fixtures				**TPS implants**			
	Distal			Mesial	Mesial			Distal
Dog 1	10	10	7	7	6	6	10	10
Dog 2	10	10	7	7	6	6	6	10
Dog 3	10	10	7	7	6	10	10	10
Dog 4	7	7	10	10	6	10	6	10

Table 1. Implant distribution of the machined-surface Brånemark and TPS-coated Straumann implants.

2.3. Clinical evaluation, radiographic examination and removal torque measurements

Three months after implant placement, the soft tissue condition was evaluated at each maxillary segment. A mid-crestal incision was performed for the Brånemark submerged fixtures, a sulcular incision for the non-submerged Straumann implants. Each posterior maxilla was exposed by reflecting a muco-periostal flap and implant stability was clinically tested. The maxillary bone segment containing the implants was resected, radiographed and then secured in a bench-vise. The cover screws were carefully removed and a customized device (Straumann AG, Basel, Switzerland) was screwed on the implants to allow application of the reverse-torque. Within half-an-hour after bone resection, implant anchorage was assessed with a HSIOS HD 100 portable digital torque-meter (Intechnik, Adliswil, Switzerland). After resection of the last bone segment, the dogs were sacrificed with a lethal dose of Dolethal® (Laboratoire Vetoquinol, Paris, France).

2.4. Statistical analysis

The reverse-torque values were statistically evaluated with a 1-way analysis of variance (ANOVA) taking the implant as the analyzed unit. The Student-Neumann-Keuls method was used for pairwise comparisons. Differences were considered significant at $p<0.05$.

3. Results

3.1. Soft tissue condition and implant stability

All the Brånemark fixtures remained submerged without mucosal ulceration; the Straumann implants remained uncovered with the soft tissues in good condition. All implants were clinically stable without peri-implant radiolucency on the radiographs.

3.2. Straumann TPS implants removal torque measurements

During maxilla resection of the first dog, the distal bony wall of the most distal implant was torn-off accidentally, excluding this implant from analysis **(Table 2)**. During removal torque application, implants held firmly in the bone until loosening; the peak torque value was reached without early signs of discernible mobilization. A steep decrease in

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removal torque value followed **(Figure 3)**. For the 10 mm long implants, the mean reverse-torque value was 90.14 ± 14.60 Ncm; it was 55.13 ± 23.94 Ncm for the 6 mm long implants **(Table 2)**. Increasing implant length by 4 mm (66.7%) enhanced significantly implant anchorage by 63.5% **(Table 3)**.

	TPS implants		**Machined fixtures**			
	peak torque		mobilization torque		peak torque	
	6 mm	**10 mm**	**7 mm**	**10 mm**	**7 mm**	**10 mm**
Dog 1	92	82	34	12	42	30
	50	-	10	18	26	30
Dog 2	60	74	16	16	46	36
	34	93	26	19	27	30
Dog 3	12	101	26	18	33	35
	67	98	11	24	25	45
Dog 4	59	111	9	37	12	53
	67	72	24	33	26	55
Mean	**55.13**	**90.14**	**19.5**	**22.12**	**29.63**	**39.25**
SD	± 23.94	± 14.60	± 9.26	± 8.68	± 10.68	± 10.39

Table 2. Removal torque measured for the Straumann TPS-coated implants and the Brånemark machined-surface fixtures. For the machined-surface fixtures, 2 sets of torque values are displayed, the mobilization and peak torque values. Average torque and standard deviation are given.

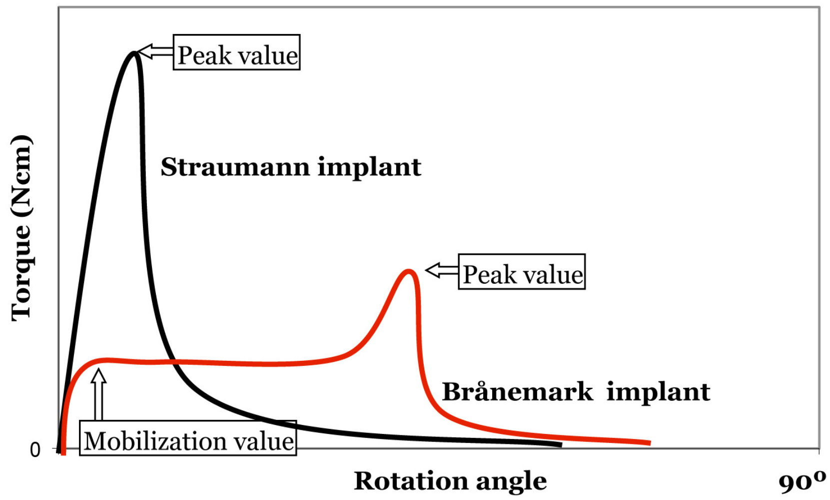

Figure 3. Schematic representation of the loosening modes of the 10 mm long Straumann and Brånemark implants. Note the mobilization torque level for the Brånemark implants, the plateau attained during the rotation phase, the peak-value and the steep decrease of the reverse-torque value.

3.3. Brånemark machined-surface fixtures removal torque measurements

In contrast to TPS implants, implant loosening of the machine-surfaced implants was progressive as shown in **Figure 3**. Implants were immobile until a certain torque was reached. Once mobilized, implants slightly rotated; while rotating, increase in torque

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resistance was minimal **(Figure 3)**. After a certain rotation angle, a peak torque value was reached; it was followed by a steep decrease. The reverse-torque at initial mobilization was recorded as the mobilization reverse-torque value; the higher reverse-torque was recorded as the peak torque value. Both torque values are given in **Table 2**.

The mean peak torque to loosen the 10 mm long implants was 39.25 ± 10.39 Ncm; the mean mobilization torque was 22.12 ± 8.68 Ncm. The mean peak torque required to unscrew the 7 mm long implants was 29.63 ± 10.68 Ncm; the corresponding mobilization value was 19.50 ± 9.26 Ncm. Increasing fixture length by 3 mm (43%) enhanced the peak anchorage by 32%, the mobilization torque increased by 13%.

Peak torque values were compared between implant systems **(Table 3b)**. The 6 mm Straumann implants were better anchored than the 7 mm Brånemark fixtures (+86%). The 10 mm Straumann implants were more firmly anchored than the equivalent Brånemark fixtures (+130%). When considering the mobilization torque for the Brånemark implants, the difference in anchorage between the 6 mm Straumann and the 7 mm Brånemark implants was +183%. The anchorage difference between the 10 mm implants of both implant systems was +307% **(Table 3a)**.

(a)	**Straumann implants** peak torque	**Brånemark fixtures** mobilization torque	
	6 mm	**7 mm**	**10 mm**
Straumann 6 mm peak torque	-	2.83 (S)	2.49 (S)
Straumann 10 mm peak torque	1.64 (S)	4.62 (S)	4.07 (S)
Brånemark 10 mm mobilization torque	-	1.13 (NS)	-

(b)	**Straumann implants** peak torque	**Brånemark fixtures** peak torque	
	6 mm	**7 mm**	**10 mm**
Straumann 6 mm peak torque	-	1.86 (S)	1.4 (S)
Straumann 10 mm peak torque	1.64 (S)	3.04 (S)	2.3 (S)
Brånemark 10 mm peak torque	-	1.32 (NS)	-

Table 3. Torque ratios and multiple pairwise comparisons according to implant length and implant system. Divisor is on the horizontal scale. **(a)** The mobilization values for the Brånemark fixtures were considered. **(b)** The peak values for the Brånemark fixtures were considered. S = statistically significant difference, NS = not statistically significant difference.

The reverse-torque values of the 2 implant groups were statistically different ($p<0.001$). A multiple pairwise comparison was performed with the Student-Neumann-Keuls method. The mobilization and peak torque values of the Brånemark implants were examined in consecutive order. When mobilization torques were examined, the means were statistically different for all implant groups, except for the 7 mm and 10 mm Brånemark implant groups **(Table 3a)**. When peak torque values were examined, the 7 mm and 10 mm Brånemark implant groups, as well as the 6 mm Straumann and the 10 mm Brånemark implant groups, were not statistically different **(Table 3b)**.

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4. Discussion

4.1. Two different anchorage/loosening modes

This study confirmed the existence of 2 distinct loosening modes in the maxilla, as previously reported in the mandible **[8]**. For TPS implants, loosening occurred at the same time as the peak reverse-torque, followed by a steep decrease in reverse-torque. This loosening mode has been associated with the rupture of a micro-mechanical bound at the implant interface. Scanning electron microscopy (SEM) and histology of the implant interface, confirmed that the TPS-coated surface displayed attached bone, and that bone fragments were found at distance from the interface **[8]**. For the machined-surface implants, a progressive loosening with 2 distinct torque values was repeatedly observed. SEM observation of the implant interface showed that the fracture line remained at the interface, no bone was found attached to the machined surface **[8]**.

These 2 patterns of loosening modes reveal 2 different forms of osseointegration. They highlight that the extreme roughness of the TPS implants promotes a very strong bone/implant biomechanical interlocking, while the machined-surface implants promote a simple surface ankylosis with limited interlocking. This difference reveals 2 different concepts of osseointegration that somehow still exist nowadays: some implant systems are promoting biomechanical interlocking while others are searching a more biochemical interlocking. However, nowadays many implant systems try to combine the 2 concepts to reach the osseointegration (for example moderate microroughness and Calcium Phosphate impregnation)**[12]**, and the 2 extremes represented by machined-surface and TPS were mostly abandoned **[9]**.

4.2. Factors influencing the anchorage

It may not be possible to identify the factors responsible for the differences in anchorage observed for these implants due to confounding differences between the 2 implant systems such as differences in design (distinct thread shape and pitch 0.6 vs. 1.25 mm), diameter (3.75 mm vs. 4.1 mm) and surface state (machined vs. TPS-coated). However, the analysis of the literature may allow us to support the surface as the main explanation of our results.

Carr et al. **[13]** compared the removal peak torque of machined-surface implants and TPS-coated implants of similar design and length, placed in the posterior maxilla of baboons. They found that TPS-coated implants were better anchored by a factor x2.2 near to the x2.3 factor measured in the present study **(Table 3a)** for Straumann and Brånemark implants of the same length. Differences in anchorage between the Straumann and the Brånemark implants may be better explained by differences in surface state (machined vs. TPS), rather than by differences in implant design (thread shape, pitch, and diameter). Noteworthy, the 10 mm long Brånemark implant has an apical hole but the 7 mm (Brånemark) implant does not have this feature. As the loosening pattern and torque values for both implant groups were similar, this suggests that the apical hole has no relevant retentive function.

Nowadays, machined-surface implants were abandoned due to their too weak biomechanical interlocking. TPS were also abandoned for various reasons that are not so clearly documented, but were mostly related to a too strong microroughness that was related with some risks of peri-implantitis **[14]**. Modern implants are mostly using an intermediate microroughness, sometimes in combination with various forms of chemical modifications **[5,9]**.

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4.3. Implant system and clinical recommendations

This study also requires to remember the evolutions of our practice with the evolution of technologies. When these surfaces were marketed, conflicting clinical recommendations have been made by Brånemark and Straumann users. For Brånemark implants, bicortical anchorage has been recommended **[10,15]**. Short implants have been considered at higher failure risk and placement of the longest possible implants privileged to take advantage of the available bone height **[15]**. In the posterior region, replacement of one implant per missing root (support value, SV = 1) has been encouraged to decrease the loading risk factor **[16]**. Long healing periods of 3-4 months in the mandible and 6-8 months in the maxilla have been mandatory **[10]**.

Unlike Brånemark implants, bicortical anchorage has not been suggested for TPS-coated Straumann implants and the 12 mm long implant is typically the longest implant inserted **[11]**. Shorter Straumann implants are not considered at higher failure risk and placement of fewer implants than the number of replaced roots (SV < 1) has been suggested **[17]**. Healing periods of 3-4 months have been recommended in both the mandible and the maxilla **[11]**.

These recommendations were based on the experience of clinicians and are supported by the current results. Nowadays, the number of new implant systems is considerable and most companies are not large enough to develop proper validated clinical recommendations. This study recalls us that differences in surface treatment promote differences in bone anchorage – particularly for short implants in the maxilla – and justify different clinical approaches. It is important to have adapted recommendations for the use of each implant system.

4.4. Implant anchorage and bone quality

The present experimental protocol was designed to obtain anchorage data from the mandible and the maxilla of the same animals. As mandible and maxilla differ in their bone structure, an aim was to observe how implant anchorage was affected by bone quality. Mandibular implants were better anchored than those inserted in the maxilla. For all implant surfaces and all implant lengths, the reverse-torque values in the mandible were roughly twice (1.74-2.13) the maxilla **(Table 4)**. In all groups, the differences in anchorage were significant when tested with the Student-t test for independent groups. Noteworthy, the TPS-coated screws inserted in the maxilla achieved at least the same anchorage as the Brånemark fixtures inserted in the mandible **(Table 4)**.

	Straumann implants peak torque		**Brånemark fixtures** mobilization torque		**Brånemark fixtures** peak torque	
	6 mm	**10 mm**	**7 mm**	**10 mm**	**7 mm**	**10 mm**
Mandible	104.88	192.25	36.67	38.57	61.88	69.13
Maxilla	55.13	90.14	19.5	22.12	29.63	39.25
Mandible/Maxilla ratio	1.90	2.13	1.88	1.74	2.09	1.76
Statistical significance	p=0.001	p=0.0001	p=0.0004	p=0.02	p<0.0001	p<0.0001

Table 4. Removal torque values of the mandibular and maxillary implants. The mandibular/maxillary torque ratio approximated 2 for all implant groups; it was statistically significant for all groups.

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The differences in anchorage between the 2 jaws might justify the recommendation for distinct healing times in the mandible and in the maxilla; indeed for Brånemark fixtures, it was advised at least 3 months of healing in the mandible and 6 months in the maxilla **[10]**. No such difference was advocated for Straumann implants since 3-4 months of healing was recommended for both jaws **[11]**. Hence, if 3-4 months of healing is appropriate in the maxilla for TPS-coated implants, a shorter healing period in the mandible may not jeopardize the integration prognosis for TPS-coated implants. Therefore, in the mandible, the 3-month healing period recommended for TPS-coated implants **[11]** could be viewed as a therapeutic reserve, as previously suggested **[8]**. The TPS-coated implants could conceivably be loaded as early as 6 weeks, like the SLA (sandblasted with large grit and acid attacked) implants, since similar torque data after 4, 8 and 12 weeks have been reported for TPS and SLA implants in mini-pigs **[18]**.

The differences in anchorage, due to bone quality and site (mandible or maxilla), corroborate the common knowledge to adjust healing times to bone quality. Thus, implants inserted in type IV bone might require a longer healing time than implants inserted in type I or II bone.

Finally, it is important to keep in mind that the implant design and bone osteotomy are also important factors, combined with the surface treatment of the implants. It can be expected that the right combination of these various elements can allow us to improve and accelerate the anchorage of new generations of implants, whatever the bone quality **[19,20]**.

5. Conclusion

In conclusion, distinct failure modes and different levels of anchorage were measured for machined-surface and TPS-coated implants. The present data suggest that the differences in anchorage are more likely due to differences in surface than to differences in implant design. This study illustrates the importance of the implant system characteristics for the adequate clinical use of short implants in the maxilla, and the need for proper recommendations depending on each system on the market.

Disclosure of interests

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