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Effect of mini-implant length and diameter on primary stability under loading with two force levels

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SUMMARY Mini-implants are widely utilized as anchorage units in orthodontic treatment. Nevertheless, there are factors that interfere with their clinical performance. The aim of this study was to examine the impact of length and diameter on the primary stability of two different types of orthodontic mini-implants loaded with two force levels.

A total of 90 self-drilling mini-implants were inserted in bovine ribs *in vitro*, 62 of which were used in data analysis. The mini-implants were of two types, Aarhus ($n = 29$) and Lomas ($n = 33$), of two lengths (7 and 9 mm, $n = 26$ and $n = 28$, respectively), and of two diameters (1.5 and 2 mm, Lomas only, $n = 6$ and $n = 8$, respectively). A closed nickel–titanium (NiTi) coil spring was attached to each mini-implant. Half of the preparations were loaded with a low force of 0.5 N and the other half with a force of 2.5 N. Mini-implant deflections during force application were non-invasively registered using a three-dimensional (3D) laser-optical system. The results were analysed with analysis of variance for the effects of implant type, implant length, and force level, and with a *t*-test for the study of the effect of diameter in two different diameter variants of the same (Lomas) implant.

In the low-force group, implant displacements were not statistically significant difference according to the investigated parameters. In the high-force group, the 9 mm long mini-implants displaced significantly less (10.5 ± 7.5 m) than the 7 mm long (22.3 ± 11.3 m, $P < 0.01$) and the 2 mm wide significantly less (8.8 ± 2.2 m) than the 1.5 mm implants (21.9 ± 1.5 m, $P < 0.001$). The force level at which significance occurred was 1 N. The rotation of the Lomas mini-implants in the form of tipping was significantly higher than that of the Aarhus mini-implants at all force levels. Implant length and diameter become statistically significant influencing parameters on implant stability only when a high force level is applied.

Introduction

Several methods have been developed to overcome the critical problem of anchorage in orthodontics. Among them, skeletal anchorage systems have received increasing interest. Starting with the use of vitalium screws (Gainsforth and Higley, 1945), and progressing to conventional osseointegrated implants that have been used as orthodontic anchorage (Roberts *et al.*, 1989), mini-plates (Jenner and Fitzpatrick, 1985), onplants (Block and Hoffman, 1995), palatal implants (Wehrbein *et al.*, 1996), mini-implants (Kanomi, 1997), and miniscrews (Costa *et al.*, 1998), these adjuncts are useful aids in achieving treatment objectives. Mini-implants are preferred because of their comparatively small size, which allows for an increase in potential intraoral placement sites, even interdentally between the roots. Due to their small dimensions, placement and removal are simple and surgical trauma is restricted to a minimum. This means shorter chair-time and less pain and discomfort, while low cost and immediate loading are additional advantages.

The failure rates of mini-implants described in the literature show great variation since retention of mini-implants in bone depends on many different factors. Some of these have been reported to be implant type, implant dimensions (Fritz *et al.*, 2003; Berens *et al.*, 2006; Tseng *et al.*, 2006), implant surface characteristics (Kim *et al.*, 2009), insertion angle (Wilmes *et al*, 2008a,b), drilling hole size (Gantus and Phillips, 1995), insertion torque (Motoyoshi *et al.*, 2006), force magnitude (Cheng *et al.*, 2004), location (Tseng *et al.*, 2006; Wiechmann *et al.*, 2007), soft tissue characteristics (Cheng *et al.*, 2004), bone quality (Stahl *et al.*, 2009), potential inflammation of the peri-implant area (Miyawaki *et al.*, 2003), and root proximity of the implant.

Another parameter, which plays a role in mini-implant retention to bone, is primary stability. The literature in the broader field of dental implantology is supportive of the significant effect of implant primary stability, which determines its long-term survival. Primary stability is defined as implant stability immediately after insertion in the bone, whereas secondary stability develops because of bone remodelling. Primary stability is due to the mechanical contact between implant and bone, which also depends on some of the abovementioned factors; implant design (Kim *et al.*, 2009), bone quality (Motoyoshi *et al.*, 2006), implant site preparation (Okazaki *et al.*, 2008), and insertion angle (Wilmes *et al.*, 2008a,b). Primary stability is measured in most studies by means of the maximum insertion torque or pull out strength. In the present research, a different method was used.

The aim of this study was to investigate the influence of implant length and diameter on the primary stability of two different types of orthodontic mini-implants, by measuring their deflections during high- and low-force application *in vitro*.

Materials and methods

A total of 90 conical-shaped titanium mini-implants from two different companies, Aarhus (American Orthodontics, Sheboygan, Wisconsin, USA) and Lomas (Mondeal, Mühlheim, Germany) miniscrews with an identical design were selected for this study. Each type of mini-implant was available in two different lengths (7 and 9 mm) and a diameter of 1.5 mm. Lomas pins of 7 mm length with a wide diameter of 2 mm were also investigated, in order to examine the influence of diameter width on implant stability (Figure 1). The final sample consisted of 62 carefully selected preparations (29 Aarhus and 33 Lomas mini-implants) since 28 mini-implants were not included in the final data analysis due to incorrect insertion (8), incorrect model preparation (9), fracture of implant during insertion (4, equally distributed between the two types), or increased noise effects in the measurements (7). The above excluded mini-implants are not an indication of the failure rate of mini-implants since most of them were excluded only due to inconsistency with the specific experimental design. The final number of mini-implants of each group is described in detail in Tables 1–3.

Fresh segments of bovine ribs segmented into a number of small bone pieces, which served as placement sites for each mini-implant were used (Figure 2). Cortical bone thickness (CBT) was around 2 mm as measured clinically. Bovine ribs present the same architectural pattern as the human mandible, with clearly defined cortical and cancellous bone. Investigations have shown that bovine ribs are the material of choice in case studies focusing on maxillofacial implantation and especially in those

Figure 1 The tested mini-implants, from the left: Aarhus 1.5 × 7 mm and 1.5 × 9 mm; Lomas 1.5 × 7 mm, 1.5 × 9 mm; and Lomas 2 × 7 mm.

Table 1 Variable Dx (mini-implant displacement along the *x*-axis). Descriptive statistics of two implant lengths.

Dependent variable: Dx (m)

Length (mm)	Force (N)	Mean	SD	*N*
7	0.5	6.2	3.3	14
	2.5	22.4	11.3	12
	Total	13.7	11.4	26
9	0.5	5.3	1.1	14
	2.5	10.5	7.5	14
	Total	7.9	5.9	28
Total	0.5	5.7	2.4	28
	2.5	15.9	11.0	26
	Total	10.7	9.3	54

Table 2 Variable Ry (mini-implant rotation around the *y*-axis). Descriptive statistics of two implant types.

Dependent variable: Ry (^{0})

Type	Force (N)	Mean	SD	*N*
Aarhus	0.5	0.011	0.007	15
	2.5	0.064	0.033	14
	Total	0.037	0.035	29
Lomas	0.5	0.021	0.010	13
	2.5	0.121	0.037	12
	Total	0.069	0.057	25
Total	0.5	0.016	0.009	28
	2.5	0.090	0.045	26
	Total	0.052	0.049	54

Table 3 Variables Dx and Ry (Dx, mini-implant displacement along *x*-axis and Ry, mini-implant rotation around *y*-axis). Descriptive statistics of two implant diameters.

Dependent variables: Dx (m) and Ry (^{0})

Diameter (mm)	Force (N)	Variables	Mean	SD	*n*
1.5	0.5	Dx	6.9	2.4	3
		Ry	0.019	0.006	
	2.5	Dx	21.9	1.6	3
		Ry	0.130	0.005	
2	0.5	Dx	5.6	3.5	5
		Ry	0.007	0.008	
	2.5	Dx	8.8	2.3	3
		Ry	0.070	0.023	

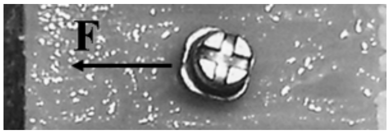

Figure 2 Mini-implant inserted in a bovine bone segment. The force axis was parallel to the bone surface and perpendicular to the long axis of the animal rib.

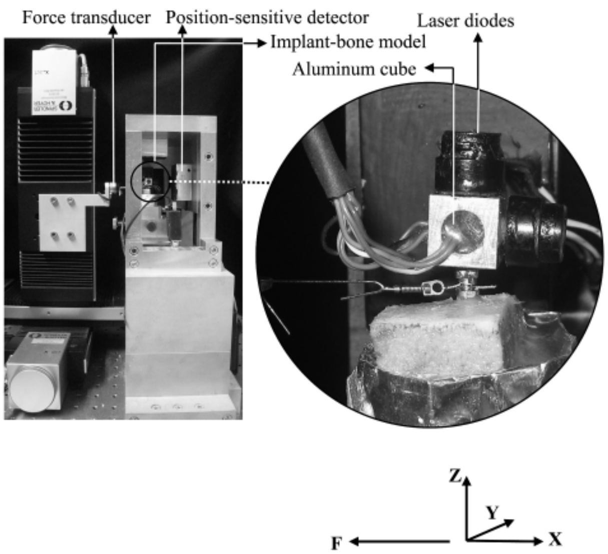

Figure 3 Preparation mounted in the optomechanical system. Force application was applied via a nickel–titanium closed coil spring.

comparing the biomechanical performance of similar dimension rigid fixation systems in terms of stability (Bredbenner and Haug, 2000). The self-drilling mini-implants were inserted into the bone segments using the tools provided by the respective companies.

Following implant insertion, the models were fixed in a standard metallic cube using an autopolymerizing acrylic resin (Palavit G; Heraeus Kulzer GmbH, Hanau, Germany). The preparations were then transferred and mounted in a three-dimensional (3D) mobility measurement system (MOMS; Hinterkausen *et al.*, 1998). The MOMS consists of two components, a mechanical and a laser-optical subsystem (Figure 3). The mechanical system, for load application, is split into three basic components: a force/torque transducer (ATI FT Nano 12; Schunk GmbH & Co. KG, Lauffen/Neckar, Germany), a stepping motor-driven positioning table, and a computer. The laser-optical subsystem registers the implant displacements and rotations in all three coordinates. This is achieved by an aluminium cube equipped with three laser diodes on three sides. The laser beams of the cube were focused on planar positioning sensing detectors. The data collected were subsequently shown as force/deflection curves. The laser system was fixed on top of each mini-implant with an instant adhesive (Sekundenkleber, Pluradent, Germany) thereby defining a Cartesian rigid body coordinate system. The light weight of the cubes ensured that no pre-load was applied on the mini-implant.

Force application

Force was applied on the mini-implants through nickel–titanium (NiTi) closed coil springs (American Orthodontics). The springs were attached to the neck of the mini-implants on one side and on the mechanical 3D force/torque transducer on the other, via wire ligatures. The force axis was parallel to the bone surface (Figure 3). The direction of force according to bone elements was perpendicular to the long axis of the animal rib. Two force levels were used: half of the mini-implants were loaded with 0.5 N and the other half with a force up to 2.5 N. Forces were gradually increased from zero to the corresponding maximum point (0.5 or 2.5 N). Maximum load was applied in a total of 10 and 20 incremental steps, respectively. Implant displacement and rotation were measured at every step during loading and were available in all three coordinates. The objective of this study was focused on mini-implant displacements (Dx) along the direction of force (x-axis) and on mini-implant rotations (tipping movement) around the y-axis (Ry). Each measurement was repeated twice by the same author (AC) to examine possible intra-observer error. The fresh bone segments were kept moist throughout the experiment by rinsing in 0.9 per cent saline solution.

Statistical analysis

The experimental error was calculated by testing intra-observer agreement between the first and second measurement of the same preparation using the Bland–Altman test (Bland and Altman, 1999). Mini-implant displacements along the x-axis (Dx) were registered in micrometres and mini-implant rotations around the y-axis (Ry) in degrees. Descriptive statistics, including the lowest and highest values of each group, were performed. The experimental results were also displayed as box–whisker plots. To analyse the parameters of implant type, implant length, and force level, analysis of variance (three-way ANOVA) was used. To examine the effect of implant diameter, only the Lomas mini-implants of the same length (7 mm) and of two different diameters were analysed, using the independent t-test. Statistical analysis was performed with the Statistical Package for Social Sciences version.15 (SPSS Inc., Chicago, Illinois, USA) and Stata (StataCorp., LP, College Station, Texas, USA) software, at the 0.05 significance level.

Results

The study of intra-observer agreement for the whole sample did not show statistically significant differences ($P > 0.05$) in displacement (Dx) or rotation (Ry) values between the first and second measurement of the same preparation. Thus, mean displacement and mean rotation from the two measurements were calculated for each mini-implant and this value was used for further analysis. Box–whisker plots of displacements and rotations of the Aarhus and Lomas mini-implants under the effect of different lengths and forces are shown in Figure 4, and the effect of different implant diameters on displacements and rotations in Figure 5.

Low force level (F = 0.5 N)

Values of mini-implant displacement (Dx) and rotation (Ry) ranged from 3 to 11 m (mean 5.7 m) and 0.003–0.04 degrees (mean 0.02 degrees), respectively (Tables 1 and 2). ANOVA did not show statistically significant differences in displacement (Dx) according to implant type, length, or diameter when a low force level was applied (Figures 4a and 5a). In contrast, the rotation (Ry) values showed statistically significant differences between the two implant types, with the Lomas mini-implants tending to rotate significantly more (mean 0.02 degrees) than the Aarhus mini-implants (mean 0.01 degrees, $P < 0.001$; Figure 4b).

High force level (F = 2.5 N)

When a high force was applied to the implants, a different biomechanical performance was observed. The mean values of displacement (Dx) and rotation (Ry) were as expected correspondingly higher and ranged from 5 to 43 m (mean 15.9 m) and 0.006–0.17 degrees (mean 0.09 degrees), respectively (Tables 1 and 2; Figure 4a). ANOVA showed a statistically significant difference in displacement (Dx) according to implant length. The 9 mm long mini-implants were displaced significantly less (mean 10.5 m) than the 7 mm mini-implants (mean 21.9 m; $P < 0.01$) as shown in Figure 4a and Table 4, indicating better primary stability. The Ry values again showed that the Lomas mini-implants rotated significantly more (mean 0.12 degrees) than the Aarhus mini-implants (mean 0.06 degrees, $P < 0.001$; Figure 4b and Table 5). Apart from implant length, diameter was also an influencing factor for implant stability since the 2 mm wide mini-implants were also displaced and rotated significantly less (mean 8.8 m and 0.07 degrees) than the 1.5 mm wide implants (mean 21.9 m and 0.130 degrees; $P < 0.05$, Figure 5a and 5b and Tables 5 and 6).

Optimum force level

As shown above, the application of two different forces resulted in different levels of significance regarding the effect of the various investigated factors. Since the biomechanical performance of mini-implants was clearly defined when a high force level was applied, the question arises as to the optimum force level above which implant length and implant diameter could be influencing parameters for primary implant stability. The incremental steps from 0 to 2.5 N were divided into five 0.5 N intervals and the data were further analysed. The mean values of displacement (Dx) and rotation (Ry) of the mini-implants were again calculated for each force group separately. The same statistical analysis of variance was performed for each group. The results showed that implant length and implant diameter were significant influencing factors on implant stability when the force level exceeded 1 N.

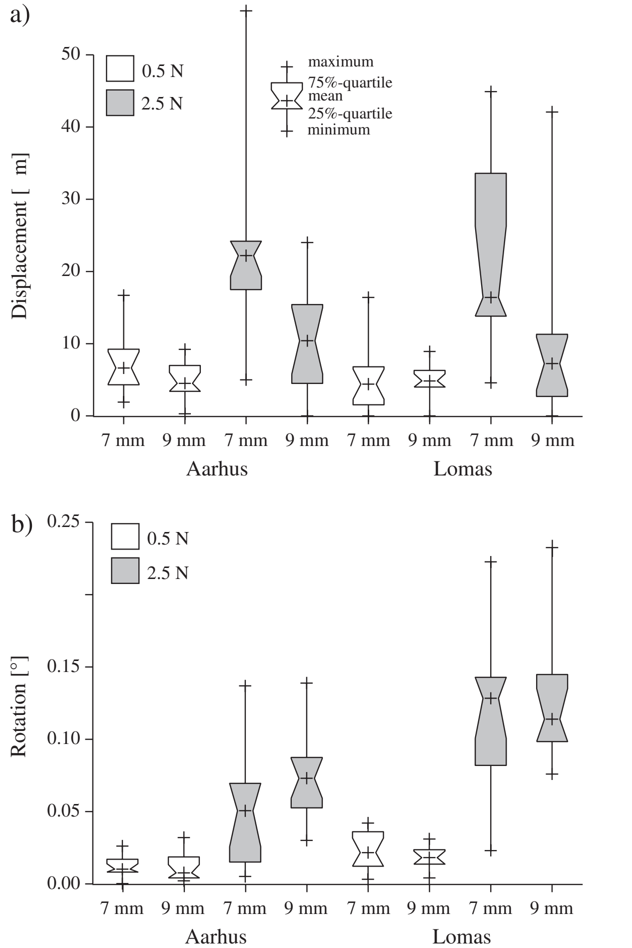

Figure 4 (a) Displacement (Dx) measured for the 7 and 9 mm long, Aarhus and Lomas mini-implants, loaded with two force levels. Statistically significant differences were observed in the high force level according to implant length ($P < 0.01$). Differences between the two implant types were not significant, (b) Rotation (Ry) of Aarhus and Lomas type mini-implant loaded with two force levels. Statistically significant differences were observed at both force levels according to implant type ($P < 0.001$).

Discussion

A review of the literature revealed different results underlying the correlations between various parameters and mini-implant stability. In this study, conically shaped

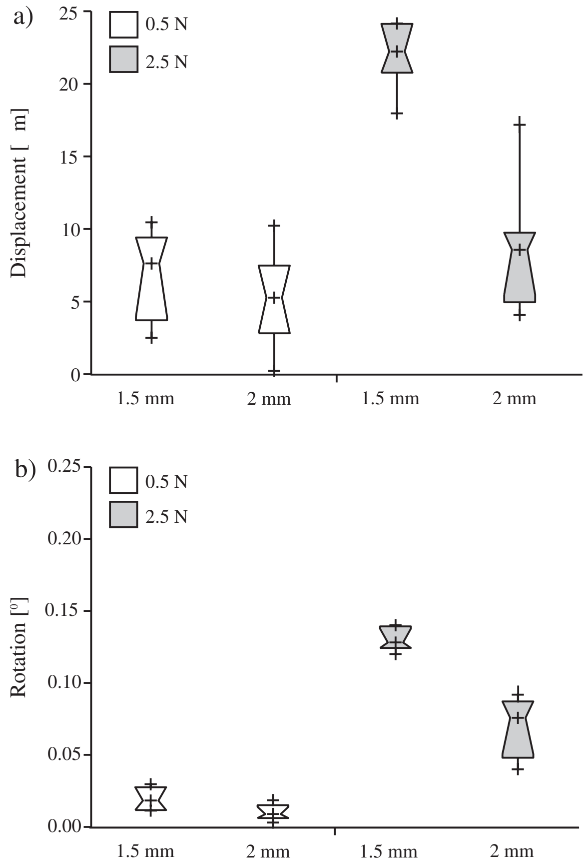

Figure 5 (a) Displacement (Dx) of Lomas mini-implants with two different diameters (1.5 and 2 mm) loaded with two force levels. Statistically significant differences were observed only in the high force group ($P < 0.001$), (b) rotation (Ry) of Lomas mini-implants of two different diameters (1.5 and 2 mm) loaded with two force levels. Statistically significant differences were again observed only in the high force group ($P < 0.05$).

mini-implants were selected instead of cylindrical ones due to their assumed primary stability. Insertion of mini-implants with the self-drilling method, as proposed by the manufacturers, was selected to exclude a pilot drilling hole since pilot hole size and depth have been found to influence primary stability of mini-implants (Gantus and Phillips, 1995). CBT and bone quality were not considered important in this study since they were almost equal for all preparations (CBT around 2 mm). According to Motoyoshi *et al.* (2009), CBT at the implant site should be 1 mm or more to improve the success rate of mini-implants.

The results showed that implant length and diameter had a significant impact on primary stability when the force level was 1 N or higher. This is the first report on the interaction of force level, implant dimensions, and implant displacements. The literature has shown contradictory results with respect to the effect of the parameters of length and diameter on mini-implant stability owing to the variability of methods and samples used. Experimental findings cannot be compared with clinical studies since *in vitro* measurements may more accurately describe the variable tested and animal bone cannot reliably substitute human bone. Clinical studies on the other hand may report clinically applicable data but do not always provide an insight into the specific details of the research hypothesis. In a clinical study, Miyawaki *et al.* (2003) reported a lack of association between the length of the screw with its stability if the screw was at least 5 mm long. Fritz *et al.* (2003) stated that 4 mm long screws offer adequate stability when compared with 6 and 8 mm screws. Cheng *et al.* (2004) did not find implant length to have a significant correlation with implant failure clinically, but in their study, length was only determined by transmucosal depth rather than by the depth of bone available for anchorage. The differences in outcome

Table 4 Mini-implant displacement (Dx) versus implant type, implant length, and force level. Statistically significant differences were observed according to implant length when a high force was applied (three-way analysis of variance).

Dependent variable: Dx

Source	Type III sum of squares	df	Mean square	*F*	Significance
Corrected model	0.002*	7	0.000	6.980	0.000
Intercept	0.007	1	0.007	134.719	0.000
Type	7.26E-006	1	7.26E-006	0.149	0.701
Length	0.001	1	0.001	11.118	**
Force	0.002	1	0.002	31.599	***
Type × length	1.92E-005	1	1.92E-005	0.394	0.533
Type × force	3.93E-006	1	3.93E-006	0.081	0.778
Length × force	0.000	1	0.000	7.893	**
Type × length × force	2.80E-005	1	2.80E-005	0.575	0.452
Error	0.002	46	4.88E-005		
Total	0.011	54			
Corrected total	0.005	53			

*Adjusted $R^2 = 0.441$.
**$P < 0.01$, ***$P < 0.001$.

Table 5 Mini-implant rotation (Ry) versus implant type, implant length, and force level. Statistically significant differences were observed according to implant type at both force levels (three-way analysis of variance).

Dependent variable: Ry					
Source	Type III sum of squares	df	Mean square	*F*	Significance
Corrected model	0.100*	7	0.014	21.953	0.000
Intercept	0.156	1	0.156	241.620	0.000
Type	0.016	1	0.016	24.029	***
Length	0.001	1	0.001	1.009	0.320
Force	0.077	1	0.077	118.244	***
Type × length	0.000	1	0.000	0.357	0.553
Type × force	0.008	1	0.008	13.054	**
Length × force	0.001	1	0.001	1.920	0.173
Type × length × force	3.72E-005	1	3.72E-005	0.057	0.812
Error	0.030	46	0.001		
Total	0.275	54			
Corrected total	0.129	53			

*Adjusted R^2 = 0.735.
**$P < 0.01$, ***$P < 0.001$.

Table 6 *t*-test for the two implant diameters concerning displacement (Dx) and rotation (Ry) versus force level. Statistically significant differences were observed according to implant diameter at the high force level.

Force (N)	Variables (equal variances assumed)	*t*-test for equality of means		
		t	df	Significance (two-tailed)
0.5	Dx	0.558	6	0.597
	Ry	2.102	6	0.080
2.5	Dx	8.035	4	0.001***
	Ry	4.341	4	0.012*

* $P < 0.05$, ***$P < 0.001$.

of the above studies compared with the present investigation can be attributed to the criteria used, meaning that mini-implant stability was mostly determined by implant mobility or complete exfoliation, whereas the present study assessed mini-implant displacements and rotations both linearly and angularly.

Differences in the results can also be explained by the applied force level. A difference was found between the implant groups when a high force of 2.5 N was applied. Further analysis of the data revealed that the level of 1 N could be defined as the threshold for differentiation. In the majority of clinical studies cited above, load application was 2 N or less and therefore no clear discrimination between force levels could be observed.

In the experimental design by Wilmes *et al.* (2006), it was again found that the length of the mini-implant does not have significant effects on their stability when measuring insertion torque. The terms 'primary stability' and 'insertion torque' seem to be used interchangeably in many publications; however, this may not be appropriate since there is still controversy over the appropriateness of the use of maximum insertion torque as a measure of implant stability.

In contrast to the above studies, Tseng *et al.* (2006) found the length of the inserted mini-implant to be an important risk factor. Those authors emphasized that the actual depth of insertion of mini-implants was more important than their length, if these measured at least 6 mm. This is in accordance with the present results as well as the general findings in the field of dental implants generally, where the shorter and smaller diameter implants had lower survival rates than the longer implants (Winkler *et al.*, 2000).

As for implant diameter, it has predominantly been found to have an impact on mini-implant stability according to both experimental and also clinical studies. Miyawaki *et al.* (2003) observed that the diameter of mini-implants was significantly associated with their stability. They reported that the 1 year success rate of implants with a 1.5 or 2.3 mm diameter was significantly greater than that of implants with a diameter of 1 mm. They also found that patients with a high mandibular plane angle showed a significantly lower success rate than those with an average or low angle due to the thinner cortical bone in the molar region. They concluded that wider implants should be placed in patients with vertical facial growth. Berens *et al.* (2006) reported that mini-implants with a 2 mm diameter had increased success rates in the mandible. They also recommended a miniscrew diameter of at least 1.5 mm in the palate. It has been suggested that implants smaller than 1.3 mm should be avoided, especially in thick mandibular cortical bone (Carano *et al.*, 2005). Nevertheless, Ohmae *et al.* (2001) showed that miniscrews with a diameter of 1 mm and a length of 4 mm placed in the mandibular third premolar region of beagle dogs were able to resist an intrusive force of 1.5 N for 12–18 weeks.

As far as implant type is concerned, the Aarhus mini-implant showed less rotation than the Lomas mini-implant at all force levels, despite the same dimensions and conical design, thus indicating better mechanical contact between the intra-osseous part of the Aarhus mini-implant and bone.

It should be emphasized that the main difference of this research compared with previous studies was that primary stability of mini-implants was examined by a direct non-invasive laser-optical measurement of its deflections, instead of indirect measurement of the insertion torque or pull out strength.

The clinical significance of the present study is high regarding the various clinical conditions and different force systems where correct mini-implant selection may be critical for their retention. Considering the multifactorial aetiology of mini-implant failure, sufficiently large implant dimensions may, under specific conditions, promote stability and should hence be selected in cases where high forces are to be applied. However, the results of this research are not supportive of the importance of a large diameter or longer length of implants in applications involving force magnitudes of less than 1 N, which are used for intrusion or indirect anchorage.

Conclusions

1. At low force levels (0.5 N), no statistically significant difference in displacement according to implant length and implant diameter was observed.
2. At high force levels (2.5 N), the 9 mm long mini-implants displaced significantly less than the 7 mm implants, and the 2 mm wide mini-implants displaced significantly less than their 1.5 mm wide counterparts.
3. The force level above which implant length and implant diameter are statistically significant influencing parameters on implant stability was found to be 1 N.
4. The rotation of the Lomas mini-implants was significantly higher than that of Aarhus mini-implants at all force levels.

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