Determination of Cantilever Length-Anterior-Posterior Spread Ratio Assuming Failure Criteria to Be the Compromise of the Prosthesis Retaining Screw-Prosthesis Joint

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The maximum cantilever length-anterior-posterior spread (CL-AP) ratio is often used as an indication of the ability to cantilever in completely implant-supported prostheses. The CL-AP ratios were determined assuming that failure occurs when the prosthesis retaining screw-prosthesis joint was compromised by either compressive (exceeding the pretorque value) or tensile (opening of the joint via plastic deformation) vertical forces using the Skalak model. Geometric arrangements of three, four, five, and six implants were analyzed. Force variables were 143, 200, and 400 N for the applied force, the pretorque value, and the joint tensile yield strength, respectively. The pretorque value was always exceeded before the yield strength. Allowable CL-AP ratios were *(1)* lower than those previously reported and *(2)* found to be 0.5 to 1.8, 0.7 to 1.6, 1.1 to 1.7, and 1.8 for three, four, five, and six implants, respectively. Although implant distributions with the highest AP often provide adequate occlusion, the results of this study indicate that the use of a single CL-AP ratio alone is not necessarily a good indicator of the ability to cantilever.
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Key words: biomechanics, dental implant, pretorque value, prosthesis retaining screw, Skalak model

Proper biomechanics is an essential factor in maintaining implant-supported prostheses.[1] Overloading may result in *(1)* a gap at the prosthesis screw-prosthesis or abutment screw-abutment interface,[2] *(2)* fracture of the prosthesis or abutment screw,[3,4] *(3)* fracture or plastic deformation of prostheses,[3] *(4)* implant fracture,[5] *(5)* loss of osseointegration,[6] or *(6)* bone fracture.[7] Loosening of the prosthesis retaining screw occurs at the lowest loads when compared to all other structural complications.[8]

The opening of a gap at the retaining screw-prosthesis interface can be the result of either excessive compressive or tensile forces.[2,9,10] During compression, joint opening can be caused by screw loosening if the pretorque value (PV) is exceeded.[9,10] The PV of a screw or bolt is the tension developed in the screw because of the applied torquing forces during screw tightening.[11] Since it is the tension in the screw that holds the clamped pieces together, if a compressive force of equal or greater magnitude is applied, screw loosening may occur.[11] Tensile forces can cause a joint opening resulting from plastic deformation of the interface components.[2] Joint openings affect the capability of the affected implant to carry loads appropriately, possibly causing higher forces on the other implants.

Cantilever length (CL) is the length of the superstructure projecting distally from the most distal implants. Anterior-posterior spread (AP) is the distance between the line connecting the two most distal implants and the center of the implant most distant to that line.[12] The AP provides a rough measure of the geometric distribution of the implants. Both CL and AP are essential factors to distribution of the occlusal loads. The CL-AP ratios of 1.5[12] and 2[13] have been suggested as guides for the maximum allowable CL. A CL-AP ratio of 2 was determined by choosing an implant force equal to twice the applied load as the failure criteria and using the Skalak model to determine the axial implant forces.[13] The 1.5 ratio was determined empirically for prostheses supported by five implants after considering some clinical conditions that might biomechanically compromise the outcome of some cases.[12]

The purpose of the present study was to determine an acceptable CL-AP ratio if failure of the prosthesis is assumed to occur by loosening of the prosthesis retaining screw for compressive implant loads and by yielding of the retaining screw-prosthesis joint for tensile implant loads. In this study, emphasis was placed on parameters that most closely simulate clinical conditions.

Materials and Methods

The vertical force distribution on fixed implant-supported prostheses over three, four, five, and six implants was analyzed. Implants were placed in positions approximately at the sites of the central incisors, canines, and first premolars, about 10 mm apart[1,13] (Fig 1). All combinations of three, four, five, and six implants on the six sites were analyzed, excluding cases that were symmetrical to others: *(1)* one case with six implants; *(2)* three cases with five implants; *(3)* nine cases with four implants; and *(4)* 10 cases with three implants. To facilitate the presentation of the results, the sites of implants were numbered from one to six from the patient's right side (see Fig 1). Cases were labeled with the implant numbers of the implants present in that case. Implants not present in a particular case are represented by a dash.

The Skalak model[1] was used to calculate vertical forces on the implants under an occlusal load of 143 N applied along the superstructure on 36 points (see Fig 1). The force on a implant (assuming rigid superstructure, rigid connections of screws to the superstructure, elastic deflection of screws, and no moment transfer between implants and prosthesis), is calculated via:

$$F_i = (P / N) + P(A_{x_i} + B_{y_i}) \qquad (1)$$

where P is the applied occlusal force, N is the number of screws, and x_i and y_i are the centroidal coordinates of the ith screw. Values *A* and *B* are geometric coefficients that depend on the location of the load *P*, x_p, and y_p as well as the screws, and are given by:

$$A = \frac{(I_{xy} - I_{xx}x_p)}{(I_{xy}^2 - I_{xx}I_{yy})} \qquad (2)$$

$$B = \frac{(I_{xy}x_p - I_{yy}y_p)}{(I_{xy}^2 - I_{xx}I_{yy})} \qquad (3)$$

$$\text{where } I_{xx} = \sum y_i^2,\ I_{yy}, = \sum x_i^2,\ \text{and } I_{xy} = \sum x_i y_i$$

Failure of the prosthesis was assumed to occur when forces on an implant were either *(1)* greater than 200 N in compression[11] or *(2)* greater than 400 N in tension.[2] The rationale for selection of these failure criteria is explained in detail in the discussion. Clinical success was assumed to occur when occlusion at, or more distal to, the second premolar was achieved.

Results

The AP, the length of the prosthesis between the most distal implants (FL), the maximum cantilever length, and the CL-AP ratios for the patient's right and left sides are given in Tables 1 to 3. Excessive forces always occurred when the occlusal load was applied to cantilever areas. Compressive forces greater than 200 N on the most posterior implant were always achieved before tensile forces greater than 400 N (Figs 2a and 2b). Therefore, maximum cantilever lengths and CL-AP ratios were determined only by exceeding the pretorque value. Plots of implant force versus position of the applied force for cases 123456 and -2345- are similar to those previously reported for these distributions[13] (Figs 2a and 2b).

In general, the range of the CL-AP ratio was 0.5 to 1.8, 0.7 to 1.6, 1.1 to 1.7, and 1.8 for three, four, five, and six implants, respectively (see Tables 1 to 3). Although there was a trend of increasing CL with increasing AP, a single CL-AP for all distributions was not found (Fig 3a). Indeed, the CL for a single AP can vary by a factor of more than 3 (Fig 3b). For one set of implant distributions, the relationship between CL and AP was fairly linear (Fig 3c). The CL-AP ratios were not proportional to either the CL or the number of implants (Figs 4a and 4b). There was an increase in CL with increasing prosthesis length (Figs 5a to 5c). The relationship between total CL (sum of the CL on both sides) and the length of the prosthesis between the two most distal implants (FL) was fairly linear and can be described by the following equations:

for three implants

$$\text{total CL} = -4.77 + (0.48 \times \text{FL}) \qquad (4)$$

for four implants

$$\text{total CL} = -8.22 + (0.71 \times \text{FL}) \qquad (5)$$

for five implants

$$\text{total CL} = -19.02 + (1.16 \times \text{FL}) \qquad (6)$$

The shorter CL on either side contained too much scatter to be considered linear.

Considering clinical failure to be occlusion more mesial to the second premolar, failure occurs at CL-AP ratios of 1.4 for 12345-, and at 0.5 to 1.4 and 0.8 to 1.3 for various cases with three and four implants, respectively (see Tables 2 and 3). Clinically successful occlusion occurred for CL-AP ratios of 0.6 to 1.8, 0.7 to 1.6, 1.1 to 1.7, and 1.8 for three-, four-, five-, and six-implant distributions, respectively (see Tables 1 to 3).

Discussion

The presence of cantilevers is one of the more important considerations in fixed implant-supported restorations. The ratio of CL to AP is believed to be a valid indicator of the ability to cantilever.[12,13] It presents a value that relates implant distribution to the maximum permissible CL. Although values of 1.5[12] and 2[13] have been suggested as acceptable, the failure force assumptions made may not be conservative enough. The results of the present study indicate that a CL-AP ratio of 2 is too high for all of the cases studied, using the arch shape in Fig 1, and that 1.5 is too high for all cases except for six implants. Also, the use of a single ratio is not correct, since the ratios varied by a factor greater than 3 (see Tables 1 to 3).

The reason that the CL-AP ratios of the present study are lower than those previously reported is the result of differences in assumed failure force. The CL-AP ratio of 2 was obtained assuming the failure criteria to be implant fracture, which was assumed to occur when the force on a implant was twice the applied load.[13] This assumption does not reflect measured occlusal forces or reported failure forces. The previously suggested ratio of 1.5, using empirical evidence and the reported value of 2, may be closer to the actual clinical situation.[12]

Failure in the present study is assumed to occur when the prosthesis retaining screw-prosthesis joint is compromised; namely, if the prosthesis retaining screws loosen (exceeding the pretorque value) or the retaining screw-prosthesis joint plastic deforms, since implant-supported prosthesis failure is believed to occur at these sites under the lowest loads.[8] The difference in failure force is significant, since failure at twice the occlusal load predicts that CL values of 28 and 12 mm are allowable for 123456 and -2345- cases, respectively,[13] whereas lengths greater than 24 and 6 mm will compromise the prosthesis retaining screw-prosthesis joint for these cases (see Tables 1 and 2).

It is the tension in the screw (pretorque value) that causes the compressive forces to hold the two fastened structures together. If a compressive force applied to the structures exceeds the pretorque value, the screw may loosen. Prosthesis retaining screws tightened in vitro to the clinically suggested 10 Ncm have pretorque values between 172 and 322 N.[2,10] The value of 200 N in the present study was selected because it represents the higher of the two pretorque values observed in cast-to as opposed to as-received cylinders,[10] in an attempt to more closely match the clinical situation. It is believed that lower pretorque values may be obtained clinically, especially in the posterior areas, since 10 Ncm may not always be obtainable in vivo (Nicholls J. Update on restorative materials. Presented at the American Prosthodontic Society Annual Meeting, Chicago, 19 Feb 1994). For example, small intraoral hand screwdrivers have been found to provide pretorque values of 140 to 186 N (Nicholls J. Update on restorative materials. Presented at the American Prosthodontic Society Annual Meeting, Chicago, 19 Feb 1994). Lower tightening torque produces lower pretorque values.[14]

In the present study, it was assumed that the fit of the superstructure is ideal and the contacts between the components are intimate. A nonpassive fit may affect the obtainable pretorque value and may provide additional loads. Other PV factors to be considered are screw material, design, and mating surfaces.[15] Load sharing between screws and components could allow for higher applied loads without screw loosening. The above clinical factors, which may produce a PV lower than 200 N, as well as possibly higher applied loads, as discussed below, were assumed to outweigh the effects of load sharing. For these reasons and others, 100 N was used in a previous study so as to more closely simulate the clinical situation.[16] Therefore, 200 N was the highest of the clinically relevant reported pretorque values, whereas the choice of another relevant value would have caused even lower calculated CL-AP ratios.

One study[2] revealed that bending moments of 80 Ncm cause an opening of the joint because of plastic deformation. In that experimental study,[2] 80 Ncm provided an axial force of approximately 400 N. Therefore, 400 N was used for the tensile failure criteria. Although tensile forces can cause joint failure, compressive failure was found to occur at shorter cantilever lengths for the geometries in the present study. Therefore, tensile failure did not affect the calculated CL-AP ratios.

The occlusal force affects the calculated CL-AP ratio. The chosen force of 143 N was the mean maximal occlusal force measured in patients with implant-supported fixed prostheses.[17] Some patients can easily apply higher forces, since the maximal bite force ranged between 42 and 412 N.[17] Also, bending moments can cause axial forces[2] in addition to those vertical forces already applied. Hence, a force of 143 N is conservative, and the use of higher applied forces would also cause lower acceptable CL-AP ratios than reported in the present study.

The calculated CL-AP ratios are also higher than actual allowable CL-AP ratios because of the use of the Skalak model, as opposed to in vitro measurements. Although the results of the Skalak model are close to the in vitro measurements and provide similar results to models by Rangert and Patterson,[18] the model was found to slightly underestimate forces on implants nearest the loading point.[19] When loads are applied to the cantilever areas, the Skalak model underestimates the actual forces on the most distal implants. Hence, the actual forces on the most distal implants are higher than those reported in the present study. It is in these most distal implants that the pretorque value is exceeded first (see Figs 2a and 2b), again causing even shorter allowable clinical cantilever lengths than reported in the present study.

The Skalak model used herein assumes equal stiffness for each implant connection. The model has been modified to include connections of varying stiffness in one prosthesis.[20] When abutments do not have the same stiffness, the force distribution may be affected dramatically. The stiffer abutments carry more of the load. This is especially true during loading of the cantilever. For example, if in a prosthesis supported by six implants, the most distal abutments are more compliant than the others and the load is applied to the cantilever, the next distal implant can be loaded three to four times more than that of an equal stiffness case.[20] Utilizing a variable stiffness model would have most likely produced a lower CL.

Despite using a comparatively high pretorque value, a low applied occlusal force, equally stiff abutments, and the Skalak model, the acceptable CL-AP ratios calculated in this study are still lower than the reported 1.5 or 2 for all cases except the six-implant prosthesis, which has a CL-AP ratio of 1.8.

Although the use of a single CL-AP ratio may not be appropriate for use in all cases, the AP still provides an indication of the ability to cantilever, since it reflects implant distribution. It has been shown that implant forces are lower with a greater tripodization in the implant distribution, providing larger AP values.[21] Therefore, since the implant forces are lower with a larger AP, such distributions should enable larger cantilever lengths. For example, 1234-- has a much smaller AP than 1-34-6. The maximum permissible CL for 1234-- is 5 mm, for the patient’s left, which is lower than the 14 mm for 1-34-6. Of course, the position of the most distal implant is an important clinical factor. A distribution with a very low permissible CL and implants placed in first molar sites is often clinically preferable to a distribution with a higher permissible CL and the posterior implants placed more anteriorly.

In addition to AP, the number of implants also plays a role in the ability to cantilever. For example, with the increase in the number of implants for distributions with the same AP (1-3--6, 1-34-6, 1234-6, to 123456), the CL increases from 7 to 24 mm (see Tables 1 to 3 and Fig 3b). Again, the CL-AP ratio alone may not be sufficient. Although the range of CL-AP ratios is similar for three and four implants (0.5 to 1.4 and 0.7 to 1.6, respectively), the range of cantilever lengths is much lower for three implants (2 to 15 mm) than for four (6 to 21 mm).

It has previously been reported[13] that for curved implant arrangements, the maximum allowable CL is approximately equal to the total curved implant arrangement length minus 20 mm (see Fig 5b). For the five-implant cases, the equation is total CL = $-19.02 + (FL \times 1.16)$; therefore, the reported equation of total CL = FL -20 mm actually underestimates the allowable CL under the conditions of the present study. In contrast, for the four-implant cases, the equation is total CL = $-8.22 + (FL \times 0.71)$; therefore, the reported total CL = FL - 20 mm is valid only for FL of less than 41 mm. Similarly, for the three-implant cases, CL= L –20 mm is valid only for FL under 31 mm.

For cases of symmetrically placed implants, such relationships of total CL versus FL are useful, since the CL on either side is one half of the total CL. For asymmetrically placed implants, knowing the total CL is not of much clinical use, since the cantilever lengths on each side are not equal (see Tables 1 to 3). Also, although the sum of the cantilever lengths on each side provides a linear relationship, there is much more scatter when considering the smaller CL, which is the more clinically significant parameter (see Figs 5b and 5c).

Conclusions

Although there is a trend of increasing CL with increasing AP, indiscriminate use of a single CL-AP ratio as an indication for the ability to cantilever may not be prudent, since CL is also a function of the number of implants and the distribution of implants between the most anterior and posterior implants. Also, previously reported CL-AP ratios may be too high for many different clinical situations.

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FIGURES

Figure 1

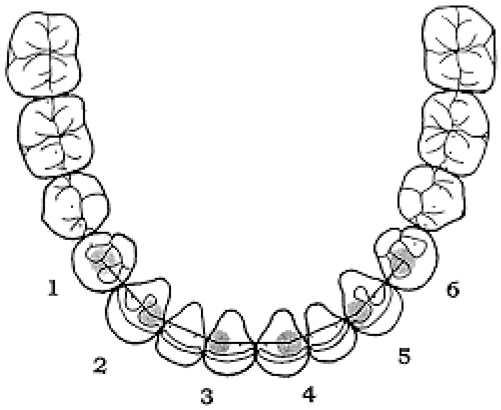
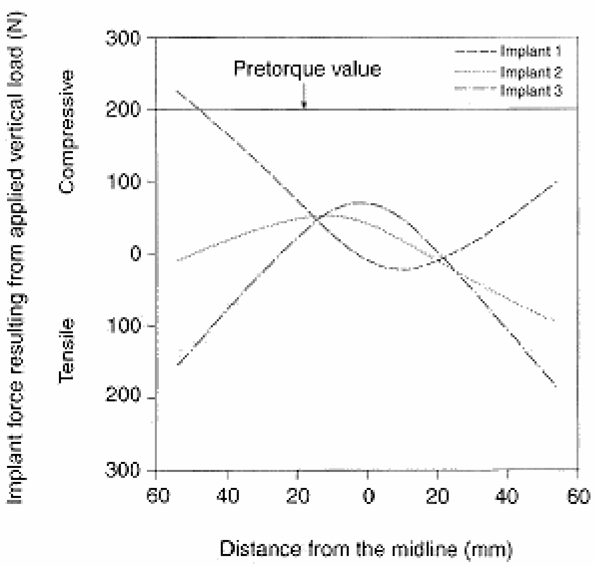


Fig. 1 Schematic representation of the six implant sites and the 36 points where the occlusal load is applied along an arch.

Figure 2a



Figs. 2a and 2b Distribution of an applied vertical load of 143 N to implants when the occlusal load is applied on individual points along the arch. Curves for symmetrically placed implants were omitted for clarity. *(Left)* Case 123456. *(Right)* Case -2345-. For all cases, the pretorque value of the prosthesis retaining screw was exceeded before the tensile yield strength of the joint.

Figure 2b

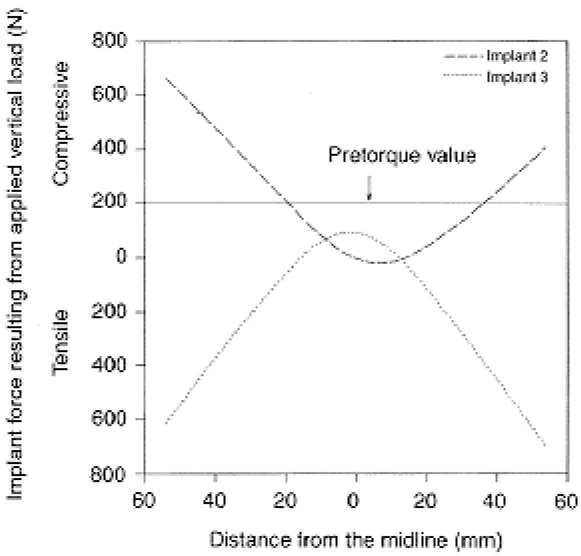


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Figure 3a

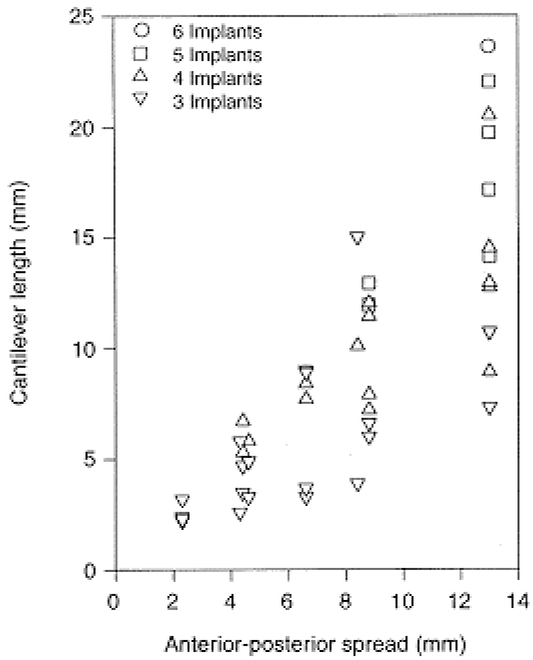


Fig. 3a Cantilever length versus anterior-posterior spread, with all implant distribution cases. Since there is no linear relationship between CL and AP, using one CL-AP ratio for all clinical cases may not provide valid results.

Figure 3b

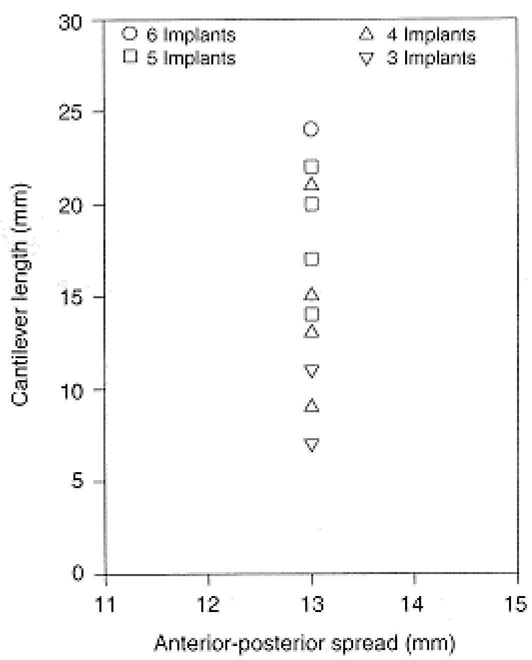


Fig. 3b All implant distribution cases with an AP of 13 mm (1-3--6, 1-34-6, 12-4-6, 123--6, 123-56, 1234-6, and 123456), showing that the CL can vary by more than a factor of three for a single AP.

Figure 3c

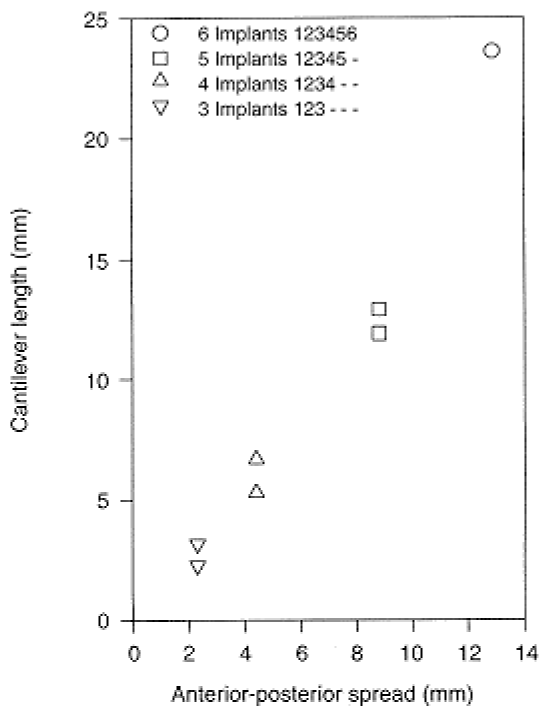
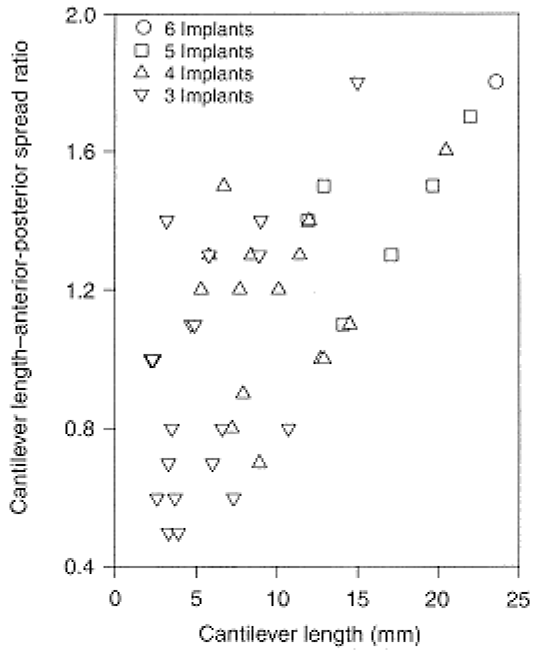


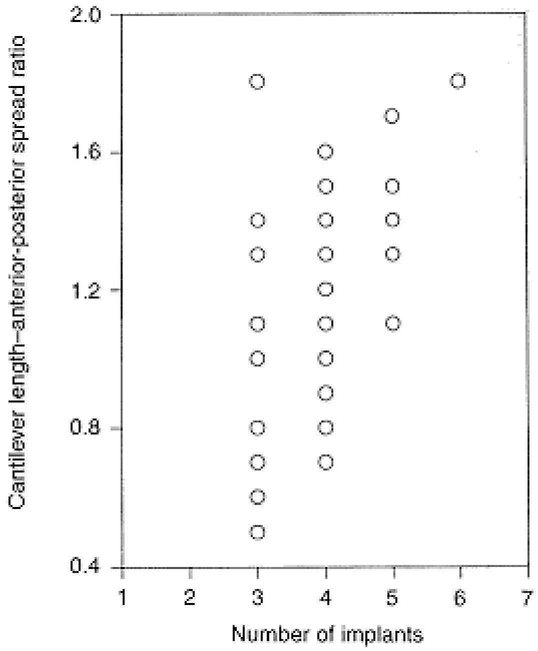
Fig. 3c Series of distributions (123---, 1234--, 12345-, and 123456) in which the relationship between CL and AP is comparatively linear.

Figure 4a



Figs. 4a and 4b The CL-AP ratios do not exhibit a linear relationship with either cantilever length *(left)* or number of implants *(right)*.

Figure 4b



Figs. 4a and 4b The CL-AP ratios do not exhibit a linear relationship with either cantilever length *(left)* or number of implants *(right)*.

Figure 5a

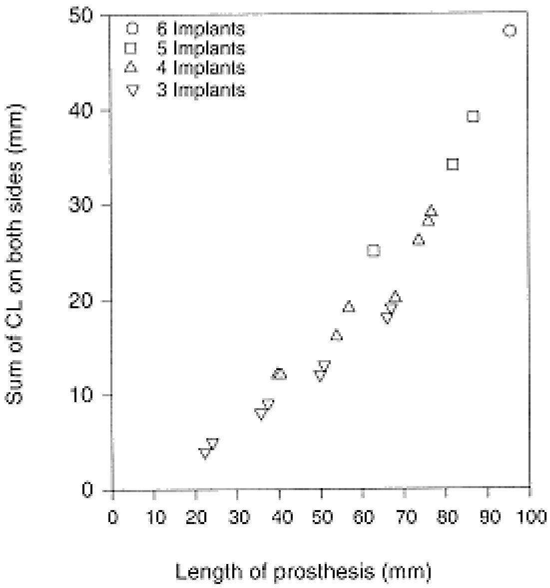


Fig. 5a Total CL (sum of the CL on both of patient’s sides) versus length of total prosthesis for all distributions.

Figure 5b

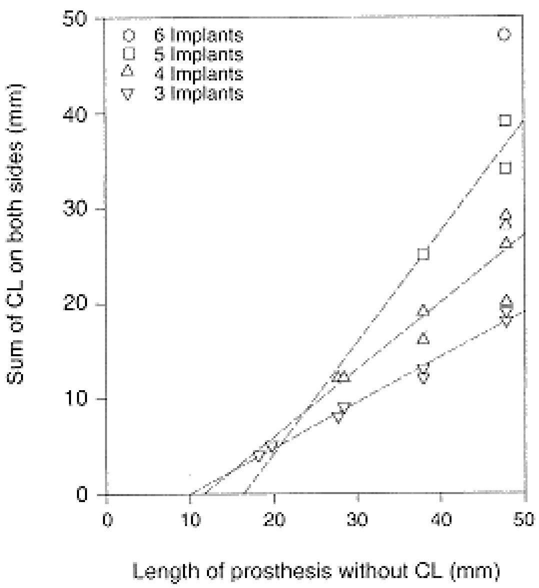


Fig. 5b Total CL versus prosthesis length without CL (FL); results are linear. If the distribution of the implants across the midplane is symmetric, such a curve may be of use in determining the maximum allowable CL.

Figure 5c

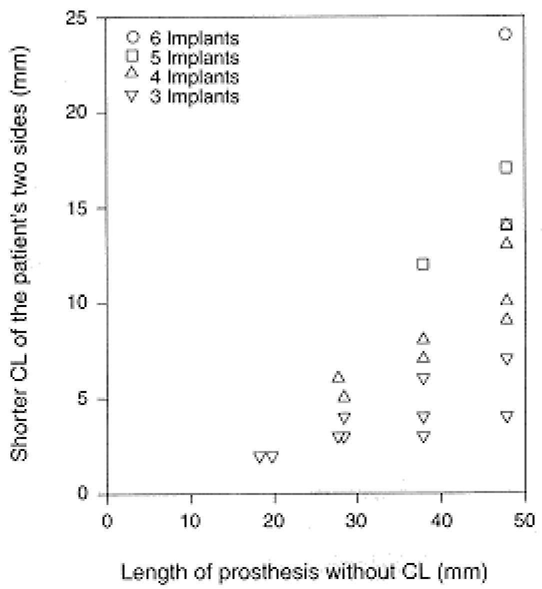


Fig. 5c Relationship between the shorter CL and the FL is not linear, since too much scatter exists.

TABLES

Table 1

Table 1 Maximum Allowable CL, AP, CL-AP Ratios, Curved Prosthesis Length Without CL (FL) for Six- and Five-Implant Cases*

Case	AP (mm)	FL (mm)	CL right	CL left	CL-AP right	CL-AP left
123456	13	48	24	24	1.8	1.8
12345-	9	38	13	12*	1.5	1.4*
1234-6	13	48	17	22	1.3	1.7
123-56	13	48	14	20	1.1	1.5

*Calculated cantilever lengths that provide occlusion more mesial to the second premolar are assumed to be clinical failures.

Table 2

Table 2 Maximum Allowable CL, AP, CL-AP Ratios, Curved Prosthesis Length Without CL (FL) for Four-Implant Cases*

Case	AP (mm)	FL (mm)	CL right	CL left	CL-AP right	CL-AP left
-2345-	5	28	6*	6*	1.2*	1.2*
1-34-6	13	48	15	15	1.1	1.1
12--56	8	48	10	10	1.2	1.2
1-345-	9	38	12	7*	1.4	0.8*
12-45-	7	38	8	8*	1.3	1.2*
123-5-	9	38	8	11*	0.9	1.3*
1234--	4	28	7	5*	1.5	1.1*
12-4-6	13	48	13	13	1.0	1.0
123--6	13	48	9	21	0.7	1.6

*Calculated cantilever lengths that provide occlusion more mesial to the second premolar are assumed to be clinical failures.

Table 3

Table 3 Maximum Allowable CL, AP, CL-AP Ratios, Curved Prosthesis Length Without CL (FL) for Three-Implant Cases*

Case	AP (mm)	FL (mm)	CL right	CL left	CL-AP right	CL-AP left
-234--	2	18	2*	2*	1.0*	1.0*
1-34--	4	28	6*	3*	1.3*	0.6*
12-4--	4	28	4*	5	0.8*	1.0*
123---	2	20	3*	2*	1.4*	1.0*
-23--6	7	38	3*	9	0.5*	1.4
1-3--6	13	48	7	11	0.6	0.8
12---6	8	48	4*	15	0.5*	1.8
-23-5-	5	28	3*	5*	0.7*	1.1*
1-3-5-	9	38	7	6*	0.8	0.7*
12--5-	7	38	4*	9*	0.6*	1.3*

*Calculated cantilever lengths that provide occlusion more mesial to the second premolar are assumed to be clinical failures.

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