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Tightness of dental contact points in spaced and non-spaced permanent dentitions

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SUMMARY One of the characteristics of normal occlusion is tight dental contact points (CPs). However, the magnitude and distribution of the tightness of a dental contact point (TDCP) in non-spaced versus spaced dentitions are unknown, as well as the mechanism controlling this arrangement. Two hypotheses were examined: the compression theory, i.e. the teeth touch each other in a compressive state; and the resistance theory, i.e. size and number of roots determine TDCP values. For the study, 60 subjects (27 men, 33 women), mean age 25 ± 4.3 years, with a complete permanent dentition and no missing teeth were divided into spaced (n = 22) and non-spaced dentitions (n = 38). For each CP, four repeated measurements of peak strain were performed with a one-month interval.

No significant differences were found between repeated measurements. All CPs demonstrated a continuous decreased TDCP in the postero-anterior direction. Consequently, in non-spaced dentitions TDCPs between molars were 100 per cent higher than incisors. The five anterior CPs of each jaw demonstrated similar TDCP values. Maxillary TDCPs versus mandibular antagonists were not significant. Mandibular TDCPs were significantly higher in men than in women (14 per cent). Anterior TDCPs were less in spaced than in non-spaced dentitions (55 per cent). Posterior TDCPs were also lower in spaced dentitions, however, to a lesser extent (25 per cent). With the exception of $TDCP_{non\text{-}spaced} > TDCP_{spaced}$, which is partially explained by the compression theory, most of the findings support the resistance theory regulating TDCP characteristics of the permanent dentition.

Introduction

Andrews' (1972) six keys to occlusion defines characteristics of normal occlusion. His fifth key requires tight contact points (CPs), i.e. CP with no space. However, this definition raises questions regarding the magnitude of a normal tight contact for each pair of teeth and the arrangement of tightness in all CPs of the dentition.

The necessity to define the normal tightness of the dental contact point (TDCP) values can be deduced from malocclusions where the normal TDCP arrangement is violated. Tooth loss will lead to migration of adjacent dental units toward the edentulous alveolar region (Hom and Turley, 1984). However, excess in the mesiodental tooth size compared with the available alveolar arch length results in crowded dentitions (Lundström, 1952; Doris *et al*., 1981; Little *et al*., 1988; Bishara *et al*., 1995). Thus, it can be hypothesized that in an ideal dental arch arrangement, an ideal array of TDCPs is present. The TDCP of all pairs of teeth has been investigated by Osborn (1961) and Southard *et al.* (1989). Any deviation in dental alignment will probably result in an aberration of normal TDCP orchestration (Southard *et al*., 1990a). A decline in normal range values of TDCPs is expected in cases with arch length excess, i.e. when the alveolar arch length is greater than the mesiodistal total of the teeth (e.g. after tooth extraction). An increase in TDCPs values is anticipated in arch length deficiency, i.e. when the alveolar arch length is smaller than the mesiodistal total of the teeth, e.g. increase in irregularity index (Southard *et al*., 1990a). Studies in this field have focused mainly on the change in tightness of dental contact points with respect to clenching (Osborn, 1961), the anterior component of force (Southard *et al*., 1989), mandibular malalignment (Southard *et al*., 1990a), postural position (Southard *et al*., 1990b), and chewing (Southard *et al*., 1992). The interface between adjacent teeth can be explained as an active tight contact due to the compressive force that each tooth exerts on its counterpart (compression theory) or teeth touching each other passively in a non-force mode, but resisting any force which tries to separate them (resistance theory).

Osborn (1961) and Southard *et al*. (1989) developed a technique to calculate the tightness of CP by measuring the frictional force developed when a metal strip located at the CP is pulled out laterally. Southard *et al*. (1989) had to exclude restored teeth in their study because of diverse coefficients of friction.

The objectives of this investigation were to develop a measuring device to assess the TDCP values; to define the normal TDCP pattern of the human dentition, i.e. determine TDCP values of all dental CPs (excluding third molars); to elucidate the influence of spaces on the remaining CPs; and to deduce which theory (compression versus resistance) regulates the TDCP pattern.

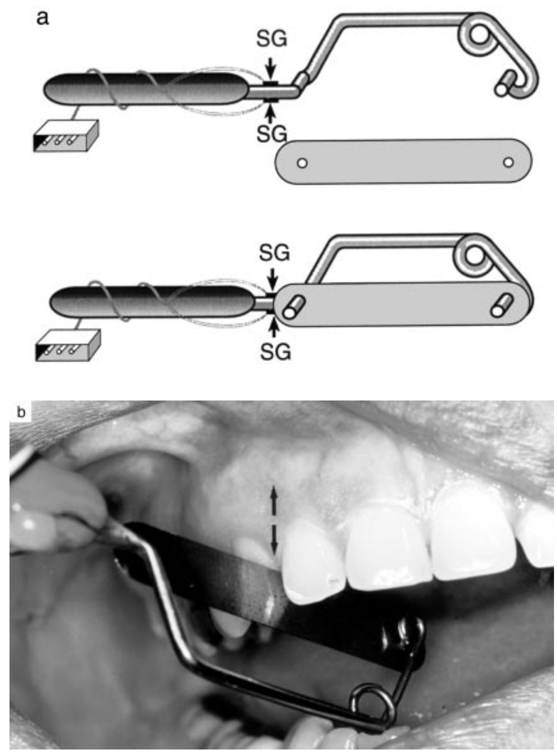

Figure 1 TDCP device. (a) Strain gauges (SG) are positioned at the base of the bow-jig close to the handle. (b) Intra-oral measurement along a vertical pathway (arrow).

Materials and methods

The tightness between adjacent teeth was measured by a newly developed TDCP device consisting of a thin metal strip, 0.05 mm thick, attached to a bow-jig (Fig. 1a). Upon insertion of the metal strip between two adjacent teeth along a vertical pathway (perpendicular to the occlusal plane), the bow-jig which bears the metal strip deflects as the metal strip slips through the CP (Fig. 1b). The amount of deformation is a function of the force needed to insert the strip between the CP, i.e. proportional to the degree of CP tightness. This deformation was measured by two uni-axial strain gauges EA-06-015DJ-120 (Measurement Group, Vishay, Raleigh, NC, USA) located on opposite sides at the base of the bow-jig close to the handle. The strain gauges were connected by a half Wheatstone bridge to a P-3500 strain indicator (Measurement Group) and the electrical signal was transmitted and expressed graphically in strain units (μS) on a BD 112 recorder (Kipp & Zonen, Delft, The Netherlands). A characteristic pattern of an increase in strain reaching a peak value and then an abrupt decrease in strain was registered (Fig. 2). The well-defined peak point was selected to describe the TDCP. As peak TDCP increases with increasing thickness of the metal strip (Southard *et al*., 1992), using the same strip thickness allows comparison between diverse dental units per person and between individuals.

The study sample consisted of 60 subjects (27 men, 33 women), mean age 25 ± 4.3 years. Criteria for selection included full permanent dentition, no missing teeth, no bridge restorations,

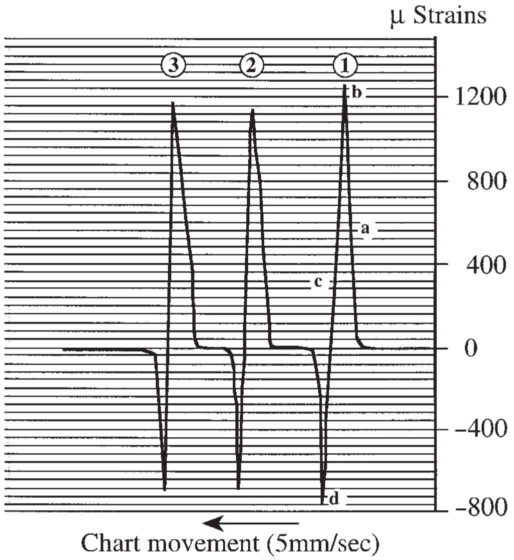

Figure 2 Three repeated TDCP charts (1–3) of the maxillary CP 1–1 of one patient. The ascending part of the curve (a) developed during forcing the metal strip in an occluso-gingival direction between contiguous teeth before penetrating the CP. The peak value (b) is achieved when CP disengagement is almost equal to the thickness of the metal strip, i.e. shortly before the metal strip starts to slip between the CP. The descending part of the curve (c) is a result of an abrupt decrease in strain when the metal strip continuously passes through the CP. A smaller anti-peak (d) develops when the strip is pulled out in a gingivo-occlusal direction.

no crowding or periodontal disease. The sample was divided into spaced ($n = 22$) and non-spaced ($n = 38$) groups. A dentition was defined as spaced if at least one CP demonstrated a TDCP level of 0 μS. For each CP, four repeated measurements were performed at monthly interval (two in each session) with the patient in a supine position. Data were analysed statistically using ANOVA with a repeated measures test and unbalanced repeated measures models with a structured covariance matrices test. The level of significance of the tests was 5 per cent ($P \leq 0.05$).

Results

In each jaw, the 13 CPs from second molar to second molar were assigned numerically according to the two adjacent teeth. For example, the CP between the first molar and the second premolar was assigned as 6–5 in all four quadrants.

Comparison between the mean values taken at the first session (two repeated measurements) and those taken at the second session (two repeated measurements), with a 1-month interval between sessions, demonstrated no significant difference for any CP. For this reason, all four repeated measurements were included in calculating the mean.

Non-spaced dentition

The normal distribution of all CPs (Table 1 and Fig. 3) demonstrated a right/left symmetry except the mandibular second-to-first premolar contact point (CP 5–4). All CPs per quadrant demonstrated a similar pattern of a continuous decreased gradient in a postero-anterior direction. This successive decrease caused the molar contact point (CP 7–6) to be two-fold greater than that of the incisors (CPs 2–1, 1–1) in both jaws. For example, the CP of the left mandibular second-to-first molar (CP 7–6) was 2697 ± 932 μS and the CP of the left mandibular lateral-to-central incisor (CP 2–1) was 1286 ± 620 μS.

Comparison between the distal and mesial CP of the same tooth (Table 2) revealed that for molars, premolars and canines, the distal CP was always significantly greater than the mesial CP in both jaws ($P \leq 0.01$). For example, for the right maxillary first molar, the distal contact point (CP 7–6) was 2743 ± 787 μS, and the mesial contact point (CP 6–5) was 2307 ± 760 μS.

Maxillary and mandibular CPs were essentially similar, with the exception of CP 5–4 for both sides and the left CP 2–1 (Table 3). In spite of these deviations, differences between juxtaposed CPs were a maximum of 10 per cent.

TDCP values of males were greater than those of females (Table 4). However, gender differences were not significant for the maxillary CPs (1–10 per cent difference) and only significant for mandibular CPs ($P = 0.049$, 8–18 per cent difference).

Spaced dentition

The mean TDCP of a given CP in the spaced group was calculated from all subjects with values greater than 0 μS, i.e. all cases with 0 μS

Table 1 Mean TDCP values (μS) of the non-spaced dentition group for right (R) and left (L) CPs in each jaw and the corresponding difference (per cent).

CP	TDCP (R) (μS)	TDCP (L) (μS)	(R–L)/R (per cent)
Maxilla			
7–6	2743 ± 787	2638 ± 580	4
6–5	2307 ± 760	2174 ± 606	6
5–4	1974 ± 630	1841 ± 669	6
4–3	1746 ± 665	1766 ± 649	1
3–2	1496 ± 597	1333 ± 571	10
2–1	1227 ± 689	1178 ± 604	3
1–1	1287 ± 667		
Mandible			
7–6	2700 ± 817	2697 ± 932	0.1
6–5	2110 ± 871	2299 ± 850	–8
5–4	1802 ± 723	2035 ± 731	–12*
4–3	1636 ± 707	1776 ± 712	–8
3–2	1312 ± 593	1407 ± 630	–7
2–1	1179 ± 600	1286 ± 620	–9
1–1	1222 ± 630		

*Right side significantly different from left side ($P \leq 0.05$).

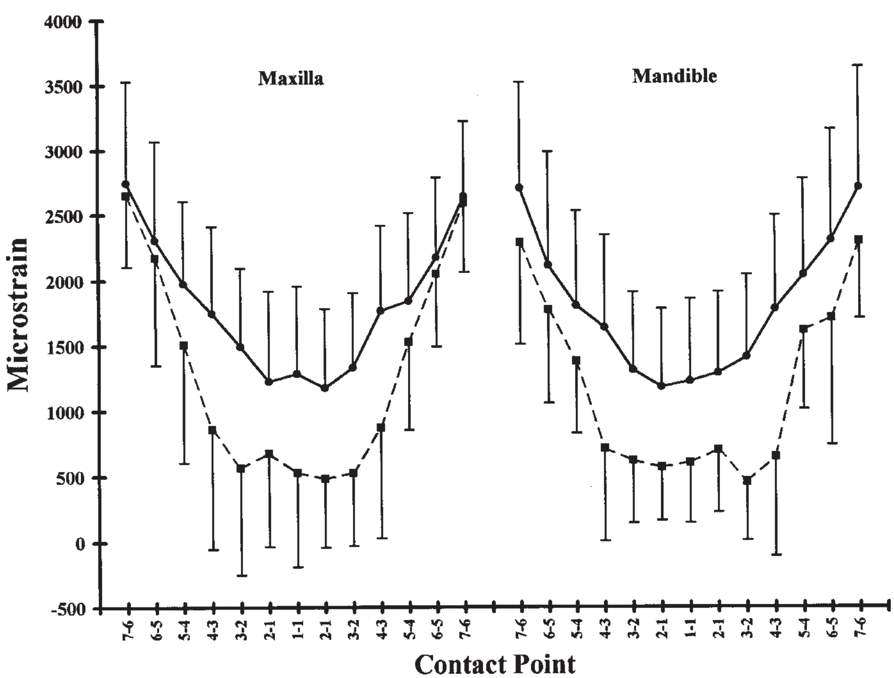

Figure 3 Diagrammatic presentation of mean TDCP values (μ strains) plotted against right and left maxillary and mandibular CPs, for the non-spaced dentition group (solid line) and the spaced dentition group (dotted line).

Table 2 Differences between mean TDCPs values (μS) of distal and mesial CPs for the same tooth in all four quadrant for the non-spaced dentition group.

CPs distal-mesial	TDCP (R) distal-mesial (μS)	Δ distal-mesial (R) (μS)	TDCP (L) distal-mesial (μS)	Δ distal-mesial (L) (μS)
Maxilla				
(7–6) – (6–5)	2743–2307	436**	2638–2174	464**
(6–5) – (5–4)	2307–1974	333**	2174–1841	333**
(5–4) – (4–3)	1974–1746	228**	1841–1766	75**
(4–3) – (3–2)	1746–1496	250**	1766–1333	433**
(3–2) – (2–1)	1496–1227	269	1333–1178	155
(2–1) – (1–1)	1227–1287	–60	1178–1287	–109
Mandible				
(7–6) – (6–5)	2700–2110	660**	2697–2299	398**
(6–5) – (5–4)	2110–1802	308**	2299–2035	264**
(5–4) – (4–3)	1802–1636	166**	2035–1776	259**
(4–3) – (3–2)	1636–1312	324**	1776–1407	369**
(3–2) – (2–1)	1312–1179	133	1407–1286	121
(2–1) – (1–1)	1179–1222	–43	1286–1222	64

**Distal side significantly different from mesial ($P \leq 0.01$).

Table 3 Differences between mean TDCPs (μS) of maxillary and mandibular CPs.

CP	TDCP (R) (μS)			TDCP (L) (μS)		
	Maxilla	Mandible	Δ (per cent)	Maxilla	Mandible	Δ (per cent)
7–6	2743 ± 787	2700 ± 817	1.5	2638 ± 580	2697 ± 932	–2
6–5	2307 ± 760	2110 ± 871	8	2174 ± 606	2299 ± 850	–6
5–4	1974 ± 630	1802 ± 723	9**	1841 ± 669	2035 ± 731	–10**
4–3	1746 ± 665	1636 ± 707	6	1766 ± 649	1776 ± 712	–0.5
3–2	1496 ± 597	1312 ± 593	10	1333 ± 571	1407 ± 630	–5
2–1	1227 ± 689	1179 ± 600	4	1178 ± 604	1286 ± 620	–9*
1–1	1287 ± 667	1222 ± 630	5	1287 ± 667	1222 ± 630	5

*Maxilla significantly different from mandible ($P \leq 0.05$). **$P \leq 0.01$.

for the given CP were excluded from the calculation (Table 5). Spaced ($n = 22$) compared with non-spaced dentitions ($n = 38$) showed significantly lower values of TDCP for all CPs except for the first molar (CP 7–6, CP 6–5) (Table 5, Fig. 3). The difference between spaced and non-spaced dentition CPs was between 45–67 per cent for the anterior region (canine–incisors) and 2–25 per cent for the posterior region (premolars, molars) in both arches. More spaces were found in the maxillary than in the mandibular arch (120 versus 38), with spaces located mainly in the anterior segment. Major spaces were found mesial and distal to the maxillary canines (CP 4–3 = 30 spaces, CP 3–2 = 36 spaces) and the maxillary diastema (CP 1–1 = 18 spaces).

Discussion

Osborn (1961) and Southard *et al.* (1989) calculated the tightness of CPs by measuring the frictional force developed when a metal strip, 0.037 mm thickness, was initially inserted interproximally (in the CP area) between two adjacent teeth and later withdrawn laterally. In contrast, the present study quantified CP tightness by measuring the force required to insert a metal strip of 0.05 mm between adjacent teeth. Whilst both techniques are valid, in the

Table 4 Comparison between genders for mean TDCPs (μS) of maxillary and mandibular CPs, for the non-spaced dentition group.

CP	TDCP (R) (μS)			TDCP (L) (μS)		
	M	F	(M–F)/M (per cent)	M	F	(M–F)/M (per cent)
Maxilla						
7–6	2798 ± 645	2700 ± 890	3	2628 ± 556	2646 ± 607	–0.6
6–5	2383 ± 679	2246 ± 825	6	2267 ± 619	2085 ± 590	8
5–4	1926 ± 613	2015 ± 677	–5	1719 ± 633	1874 ± 681	–9
4–3	1796 ± 693	1709 ± 689	5	1605 ± 631	1771 ± 654	–10
3–2	1452 ± 779	1581 ± 487	–2	1183 ± 605	1308 ± 500	–10
2–1	1235 ± 764	1223 ± 609	1	1187 ± 697	1137 ± 557	4
1–1	1218 ± 847	1331 ± 585	–9	1218 ± 847	1331 ± 585	–9
Mandible						
7–6	2886 ± 802	2547 ± 808	12	2924 ± 1012	2523 ± 836	14
6–5	2490 ± 877	2157 ± 809	13	2300 ± 951	1943 ± 750	16
5–4	2154 ± 870	1936 ± 591	10	1875 ± 748	1726 ± 702	8
4–3	1903 ± 834	1669 ± 562	12	1744 ± 897	1424 ± 465	18
3–2	1486 ± 654	1333 ± 608	11	1401 ± 702	1174 ± 479	16
2–1	1386 ± 711	1181 ± 519	15	1299 ± 708	1601 ± 462	18
1–1	1332 ± 701	1111 ± 559	17	1332 ± 701	1111 ± 559	17

Table 5 Comparison between non-spaced (NS) and spaced (S) dentitions for mean TDCPs (μS) of maxillary and mandibular CPs.

CP	TDCP (R) (μS)			TDCP (L) (μS)		
	NS	S	(NS–S)/NS (per cent)	NS	S	(NS–S)/NS (per cent)
Maxilla						
7–6	2743 ± 787	2651 ± 546	3	2638 ± 580	2589 ± 526	2
6–5	2307 ± 760	2173 ± 822	6	2174 ± 606	2045 ± 554	6
5–4	1974 ± 630	1507 ± 904	23**	1841 ± 669	1526 ± 675	17*
4–3	1746 ± 665	857 ± 913	50**	1766 ± 649	872 ± 846	51**
3–2	1496 ± 597	563 ± 817	62**	1333 ± 571	524 ± 553	60**
2–1	1227 ± 689	675 ± 710	45**	1178 ± 604	482 ± 525	59**
1–1	1287 ± 667	528 ± 719	59**	1287 ± 667	528 ± 719	59**
Mandible						
7–6	2700 ± 817	2286 ± 775	15	2697 ± 932	2290 ± 590	15
6–5	2110 ± 871	1773 ± 716	16	2299 ± 850	1704 ± 970	25*
5–4	1802 ± 723	1379 ± 550	23*	2035 ± 731	1611 ± 603	21*
4–3	1636 ± 707	709 ± 703	56**	1776 ± 712	644 ± 753	63**
3–2	1312 ± 593	617 ± 474	53**	1407 ± 630	454 ± 443	67**
2–1	1179 ± 600	566 ± 406	52**	1286 ± 620	697 ± 474	46**
1–1	1222 ± 630	601 ± 459	50**	1222 ± 630	601 ± 459	50**

*NS significantly different from S ($P \leq 0.05$). **NS significantly different from S ($P \leq 0.01$).

current method the TDCP is measured at 'real' time (during insertion), thus, no adaptation of the periodontal ligament (due to visco-elasticity) occurs. The peak TDCP measurement in the current method is minimally affected by the frictional force; the procedure is fast and easy to perform.

The low change in repeated TDCP measurements of the same CPs taken at two sessions with a 1-month interval between sessions confirms the accuracy of the measuring device and the physiological stability of the CPs array at short duration. The mean of all TDCPs values measured at the first session was 1810 μS and at the second 1818 μS, demonstrating a low mean difference of 0.44 per cent.

Non-spaced dentition

One limitation of the current method as well as that of Osborn (1961) and Southard *et al*. (1989) is that CP tightness is measured after the two adjacent teeth are separated to the thickness of the strip. Thus, the 'real' force interacting at the CP before displacing the teeth apart is unknown. Two theories are discussed in this respect:

1. The teeth touch each other in a compressive state, thus, force is required to separate a pair of teeth from their active contact (compression theory).
2. The teeth touch each other without force. However, because each tooth is firmly affixed to its own position, a force is required to displace each tooth away from the passive contact, even at minute displacement (resistance theory).

Southard *et al*. (1992) extrapolated mathematically that at 0-mm strip thickness (i.e. no strip), a compressive force of 36.7 ± 6.6 g is generated between the mandibular left second premolar and first molar (CP 6–5). Their extrapolation is based on a linear decrease in force with a decreased metal strip thickness. However, with very thin strips, a non-linear force/thickness curve can be established and the force may decrease to zero when the strip size reaches a thickness close to 0 mm. The compression theory explains only part of the reactions of CPs tightness. Migration of adjacent teeth towards an extraction site suggests the existence of a compressive force. This is supported by the low TDCPs found in spaced versus non-spaced dentitions (Fig. 3). However, diverse magnitudes of TDCPs found at various CPs in the same arch refute the compression theory. For example, in a chain of beads threaded on a straight wire and compressed at both ends, equal force will develop between each pair of beads even if the beads are of different size, if frictional forces are ignored. Thus, according to the compression theory, a common level of TDCPs should be found at all CPs in the same arch.

The results of the current study exhibit two major characteristics of normal TDCP arrangement. First, anterior TDCPs are approximately half the magnitude of posterior TDCPs and second, the distal CP of each of the posterior teeth demonstrates greater TDCP value than the mesial CP. With regard to the former, the present results are in line with the findings of Southard *et al*. (1989), which demonstrated a similar increase from anterior to posterior CPs in the maxilla (two-fold), but greater in the mandible (three-fold). The weaker TDCP values of anterior CPs suggest a condition that is prone to change over time. This change is biphasic, i.e. anterior CPs can be rearranged in the form of crowding or spacing, i.e. increased or decreased CPs tightness respectively. The first form of CP rearrangement occurs frequently in the mandible where continuous mandibular growth, together with an overbite augmentation and low TDCP predilection, allow for a lingual migration of the mandibular incisors into a smaller arch length with the consequence of crown overlapping (Fastlicht, 1970; Sinclair and Little, 1983; Gilmore and Little, 1984). The second form of CP derangement, i.e. tooth flaring, is characteristic for the maxillary incisors where initial periodontal breakdown, together with low TDCP predisposition and imbalanced muscle activity (tongue thrust, trapped lower lip, short upper lip), generates space development between incisor CPs (Graber, 1963; Posen, 1972, 1976; Proffit, 1978; Owman-Moll and Ingervall, 1984). The high coefficient of variation of anterior CPs (48 per cent) as compared with posterior CPs (34 per cent) confirms the instability of anterior CPs and the greater likelihood for one of the two mentioned responses to occur.

The result that the distal CP of each posterior tooth was greater than the mesial CP (Table 2) should not be misinterpreted as stronger periodontal support on the distal than on the mesial root of the same tooth, but rather related to the diversity in size and number of the roots of

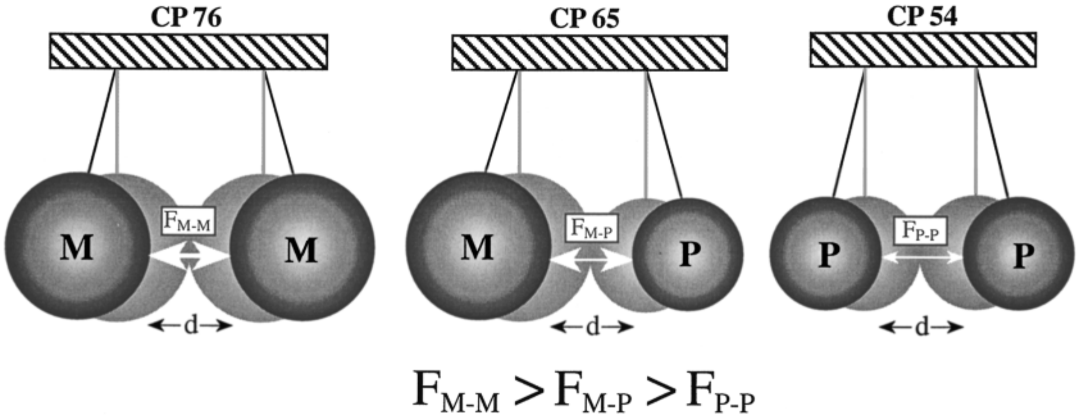

Figure 4 The greater the size of the spheres, the more force required to displace each of the three pairs of balls at a given distance (d). $F_{M\text{–}M}$ is the force required to separate the two molars (CP 7–6), $F_{M\text{–}P}$ is the force required to separate a molar and a premolar (CP 6–5) and $F_{P\text{–}P}$ is the force required to separate the two premolars (CP 5–4), implying $F_{M\text{–}M} > F_{M\text{–}P} > F_{P\text{–}P}$.

each of the two teeth building up the CP. The model of two balls, each hanging on a thread and touching each other (Fig. 4), elucidates this finding. Substituting a molar as a big ball (M) and a premolar as small ball (P), the CP 7–6 is represented by two big balls (M–M), CP 6–5 by one big and one small ball (M–P) and CP 5–4 by two small balls (P–P). The force required to displace each of these three pairs of balls at a given distance is in decreasing order $F_{M\text{–}M}$, $F_{M\text{–}P}$ and $F_{P\text{–}P}$ (Fig. 4). This corresponds with the cascade decrease in TDCP of CP 7–6, CP 6–5 and CP 5–4 in both jaws (Table 2). This cascade arrangement of posterior TDCP can only be explained by the resistance theory, suggesting that size and number of roots are major factors in determining TDCP values.

One could argue why CP 4–3 has less TDCP value than CP 5–4 (especially in the maxilla) since the canine has a greater root surface area than the premolar. It is likely that other factors overpower the impact of the canine's root size, such as the pivot location of the canine alone within the dento-alveolar arch (implying ease of canine malposition).

Another region which requires explanation is the maxillary CP 1–1. The maxillary central incisor definitely has a greater root size than the lateral incisor, yet CP 1–1 has basically the same TDCP level as CP 2–1. The fact that CP 1–1 bridges between the right and left maxillary bones with the mid-palatal suture connecting the two parts, presumably weaken CP 1–1 to a TDCP level similar to the maxillary CP 2–1 and mandibular incisor CPs. Placing two large central incisors with a pronounced root surface area is natural compensation to reinforce the weak terminal juncture between the two maxillae. Another factor that could affect CP 1–1 is the superior labial fraenum. An aberrant inferior insertion of this fraenulum intermingled with the transeptal fibres, both extending toward the incisive foramen, will frequently cause loss of maxillary CP 1–1. This could explain the relative high incidence of missing CP 1–1.

The findings of distal CP > mesial CP and the distinctive feature of posterior teeth CPs to be stronger than anterior teeth CPs, shed light on understanding of the 'mesial drift' phenomenon. Since mesial drift acts in a postero-anterior direction, greater resistance to this force component has to be provided by the posterior than the anterior dental segment. The increase in CP tightness after mastication, i.e. when mesial drift activity takes place is well demonstrated by Southard *et al.* (1989, 1992). Thus, the greater TDCP values of the molars over the incisor TDCPs (100 per cent) is a rational natural design to counteract the anterior component of mastication force.

The similarity between maxillary and mandibular TDCPs array suggests a balanced TDCPs system similar to the oral muscle equilibrium theory (Proffit, 1978). Because muscle functions, such as chewing, produce a rise in CP tightness (Southard *et al*., 1989, 1992), the effect is equally distributed between the two arches (Newton's III law). That is, if the interaction between the two dental arches delivers equal forces then the counter balancing system should be similar. However, when genders were compared (Table 4), males demonstrated higher TDCP values, especially in the lower jaw (14 per cent). This difference was significant only for the mandibular CPs and challenges the theory of equal TDCPs array in both jaws. The latter finding agrees with other studies demonstrating higher mastication forces in males over females up to 100 per cent (Waltimo and Könönen, 1993; Kiliaridis *et al*., 1995).

Spaced dentition

The mean for a given CP in the spaced group was calculated by excluding all cases with 0 μS. Thus, the reduction of CPs tightness in the spaced group reflects the influence of a missing CP on the adjacent CPs. The impact of a space in reducing the TDCP level of adjacent teeth was particularly remarkable in the anterior region (Table 5, Fig. 3). The existence of an anterior space caused a decline of approximately 55 per cent in TDCP values of all anterior CPs, including the canines in both arches. In contrast, the effect of a posterior space did not elicit a similar regional reduction (maxillary decline 20 per cent, mandibular decline 29 per cent). These findings support the resistance theory of TDCP array, i.e. the higher the TDCP level, the greater the resistance of the adjacent dental units to displacement. However, the resistance theory is in conflict with a previous finding of greater migration of posterior teeth forward than anterior teeth backward when a gap was produced (re-approximation) in *Macaca fascicularis* monkeys (Moss and Picton, 1982). The latter supports the compressive theory of TDCP arrays, i.e. the higher the TDCP level, the greater the compressive force that each tooth exerts on its contiguous tooth, causing posterior teeth to further migrate toward a space than anterior teeth. Despite this confusion, the findings of Moss and Picton (1982) do not contradict the resistance theory. The dentition is constantly affected by mastication and other physiological forces, producing the anterior component of force and mesial drift. These forces tend to shift the dentition in a postero-anterior direction. The TDCP arrangement counteracts this 'side-effect' by having the posterior dentition with a higher TDCP level (resistance theory). If a posterior space is created and if the TDCP resistance is overpowered by the mesial drift, then posterior dentition migration anteriorly will be greater than anterior dentition migration posteriorly. However, the more the space is located anteriorly, the more the effect of the mesial drift is diminished by having more posterior dental units counteracting the mesial drift with the consequence of greater migration of anterior teeth posteriorly. The low TDCP level of anterior teeth implies low resistance, i.e. greater migration of anterior teeth toward an adjacent space than posterior teeth, i.e. greater reduction in TDCPs values of anterior CPs than posterior CPs in spaced compared with non-spaced dentitions (Fig. 3).

Conclusions

The results of the present study demonstrate a distinctive pattern of CP tightness in the permanent dentition. This pattern is defined by four characteristics which are common for both dental arches:

1. CP tightness decreases progressively in a postero-anterior direction in the posterior segment.
2. Posterior TDCPs are two-fold greater than the anterior.
3. Anterior TDCPs are almost equal.
4. Maxillary and mandibular TDCPs are similar.

Two mechanism systems are suggested, which control the TDCP pattern, the compression and the resistance theories. Most findings suggest that the resistance theory governs this pattern. However, the sharp decline in TDCP in spaced dentitions suggests additional involvement of the compression theory.

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References

Andrews L F 1972 The six keys to normal occlusion. American Journal of Orthodontics 62: 296–309

Bishara S E, Khadivi P, Jakobsen J R 1995 Changes in tooth size–arch length relationships from the deciduous to the permanent dentition: a longitudinal study. American Journal of Orthodontics and Dentofacial Orthopedics 108: 607–613

Doris J M, Bernard B W, Kuftinec M M, Stom D 1981 A biometric study of tooth size and dental crowding. American Journal of Orthodontics 79: 326–336

Fastlicht J 1970 Crowding of mandibular incisors. American Journal of Orthodontics 58: 156–163

Gilmore C A, Little R M 1984 Mandibular incisor dimensions and crowding. American Journal of Orthodontics 86: 493–502

Graber T M 1963 The 'three M's': muscles, malformation and malocclusion. American Journal of Orthodontics 49: 418–450

Hom B M, Turley P K 1984 The effects of space closure of the mandibular first molar area in adults. American Journal of Orthodontics 85: 457–469

Kiliaridis S, Johansson A, Haraldson T, Omar R, Carlsson G E 1995 Craniofacial morphology, occlusal traits, and bite force in persons with advanced occlusal tooth wear. American Journal of Orthodontics and Dentofacial Orthopedics 107: 286–292

Little R M, Riedel R A, Årtun J 1988 An evaluation in mandibular anterior alignment from 10–20 years post-retention. American Journal of Orthodontics and Dentofacial Orthopedics 93: 423–428

Lundström A 1952 On the correlation between the tooth-size and the irregularities of the teeth (crowding-spacing). Archives of Orthodontics 1: 29–33

Moss J P, Picton D C A 1982 Short-term changes in the mesiodistal position of teeth following removal of approximal contacts in the monkey *Macaca fascicularis*. Archives of Oral Biology 27: 273–278

Osborn J W 1961 An investigation into the interdental forces occurring between the teeth of the same arch during clenching the jaws. Archives of Oral Biology 5: 202–211

Owman-Moll P, Ingervall B 1984 Effect of oral screen treatment on dentition, lip morphology, and function in children with incompetent lips. American Journal of Orthodontics 85: 37–46

Posen A L 1972 The influence of maximum perioral and tongue force on the incisor teeth. Angle Orthodontist 42: 285–309

Posen A L 1976 The application of quantitative perioral assessment to orthodontic case analysis and treatment planning. Angle Orthodontist 46: 118–143

Proffit W R 1978 Equilibrium theory revisited: factors influencing position of the teeth. American Journal of Orthodontics 48: 175–186

Sinclair P M, Little R M 1983 Maturation of untreated normal occlusions. American Journal of Orthodontics 3: 114–123

Southard T E, Behrents R G, Tolley E A 1989 The anterior component of occlusal force—Part I: measurement and distribution. American Journal of Orthodontics and Dentofacial Orthopedics 96: 496–500

Southard T E, Behrents R G, Tolley E A 1990a The anterior component of occlusal force—Part II: relationship with dental malalignment. American Journal of Orthodontics and Dentofacial Orthopedics 97: 41–44

Southard T E, Southard K A, Tolley E A 1990b Variation of approximal tooth contact tightness with postural change. Journal of Dental Research 69: 1776–1779

Southard T E, Southard K A, Tolley E A 1992 Periodontal force: a potential cause of relapse. American Journal of Orthodontics and Dentofacial Orthopedics 101: 221–227

Waltimo A, Könönen M 1993 A novel bite force recorder and maximal isometric bite force values for healthy young adults. Scandinavian Journal of Dental Research 101: 171–175