

Rapid maxillary expansion screws on the test bench—a pilot study

Alfred Peter Muchitsch*, B. Wendl*, H. Winsauer**, M. Pichelmayer* and M. Payer***

*Department of Clinical Orthodontics and Dentofacial Orthodontics, Medical University Clinic of Graz, **Private Practice, Bregenz and ***The Institute for Testing and Research in Materials Technology, Technical University of Graz, Austria

Correspondence to: Dr Alfred Peter Muchitsch, Department of Clinical Orthodontics and Dentofacial Orthodontics, Medical University Clinic of Graz, Auenbruggerplatz 12, A-8036 Graz/LKH, Austria. E-mail: alfred.muchitsch@medunigraz.at

SUMMARY In order to apply high, short-term forces during rapid maxillary expansion (RME) to the sutures of the maxilla with minimum loss of force and without causing unwanted side-effects (dentoalveolar tipping, etc.), the appliance should be as rigid as possible. The retention arms of the RME screws, representing a particularly vulnerable and stressed weak point of RME appliances, were the focus of this laboratory technical study. Retention arms of 16 types of RME screws comprising four arms and one with eight arms were examined using a three-point bending test. According to their ability to absorb the applied bending loads, the screws were classified in product groups from 1 (highest) to 6 (lowest).

Fifteen of the tested retention arms (stainless steel), despite having the same diameter (1.48–1.49 mm), differed up to 69.81 per cent between the highest (288.0 N) and lowest (169.6 N) maximum force parameters and up to 66.40 per cent between the highest (3325.9 N/mm²) and lowest (1998.7 N/mm²) maximum bending stress parameters. Due to optimum formability, though reduced rigidity, a titanium screw for nickel-sensitive patients (group 6) displayed the lowest force and bending tension values. The stainless steel double arms of the eight-arm screw device welded on both ends displayed the highest force data. The mean ductilities of the groups with the most and least rigid single steel arms differed by 22.77 per cent. Statistical analysis using the Pearson correlation coefficient revealed a significant indirect correlation between ductility and both maximum force ($r = -0.780$, $P < 0.001$) and maximum bending stress ($r = -0.778$, $P < 0.001$). The SUPERscrews, the Tiger Dental four-arm screw (group 1), and the eight-arm screw displayed the highest capacity to absorb an applied bending load. The screws in groups 3–6 appear acceptable for RME during the pre-pubertal period, whereas in the pubertal and post-pubertal period, groups 1 and 2 are sufficient. In early adulthood only the screws in group 1 and especially the eight-arm screw seem advisable, as mechanical demands increase with age.

Introduction

Expansion devices, however constructed, are subjected to an intense level of mechanical stress during rapid maxillary expansion (RME). A characteristic feature of this type of expansion is the short-term application of high force levels. The outcome of this robust procedure is rupture between the two maxillary halves in the area of the median palatal suture. The goal of the procedure is to create additional transverse space in the area of the apical base without, at the same time, provoking a significant level of dentoalveolar reaction, for instance, tipping of the teeth (Fürthauer and Droschl, 1981).

In order to achieve this result in practice, stable expansion devices are necessary, which meet these particular biomechanical demands. The most important construction prerequisite is sufficient rigidity of the device to apply these high forces with a minimum of tipping (Timms, 1986) and without force attenuation to the palate seam and body of the jaw. The way in which the RME device is attached to the teeth is also important. With regard to the anchoring

medium, the cemented appliance is the established standard for RME (Haas, 1965; Spolyar, 1984; Winsauer and Richter, 1990; Asanza *et al.*, 1997).

A number of factors are important for the stability of the device itself. While bands are connected with the retention arms under high temperature in only a very small area, the splint devices (Figure 1a) significantly increase the rigidity of the expansion appliances through a more extensive connection to the polymer-embedded retention arms without the need for a high temperature. They also expand both maxillary halves in a more bodily and symmetrical manner (Alpern and Yurosko, 1988). This procedure is also well fulfilled by splint devices (Figure 1a), which, provided the necessary preconditions are met, can cover all of the teeth. In addition, most appliances with metal bands use only four abutment teeth, while splint devices can cover all posterior and, provided correct diagnosis, all anterior teeth. Above all, splint devices enable problem-free anchorage of the primary teeth in the mixed dentition (Figure 1a).

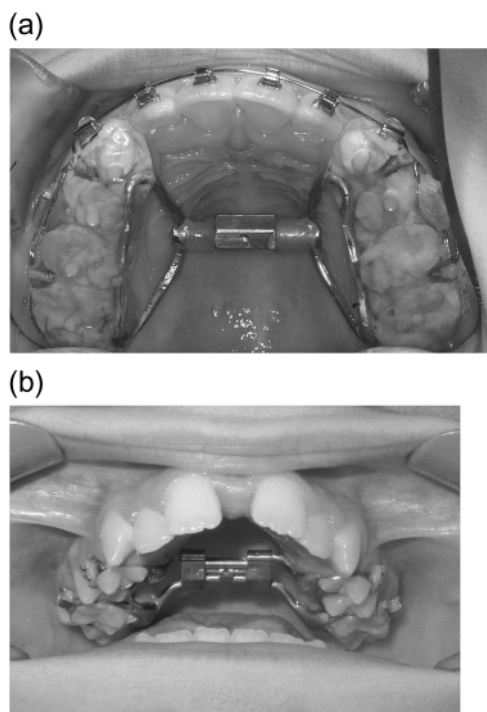


Figure 1 Cemented splint appliance (a) and Hyrax-type device (b) for rapid maxillary expansion.

The construction of the expansion appliance is important and the central factor determining the rigidity and controllability of the device. While various springs, for example, Quadhelix, W, Porter, and Coffin, reduce the rigidity of the expansion device (Timms, 1986), the RME screws that are widely used today display overall higher rigidity, although not in all parts of their design. Thus, owing to design features, such as the housing, the winding spindle, and the guide pins, the screw body forms a relatively stable part of the construction. However, the four retention arms in contrast appear significantly more unstable based on their dimensions, their exposed position, and the high degree of torque that they are subjected to during RME.

The clinical application of these screws, which are a component of various expansion devices, such as the Haas and Hyrax (Figure 1b) and bonded splint devices, has consistently revealed weak points. Thus, during RME with highly located screw bodies, yielding of the correctly pre-bent steel retention arms and the resulting contact of these or the screw body with the palatal mucosa can create pressure points (Figure 2a) or pressure ulcers (Figure 2b). The yielding of the retention arms, combined with the long non-attendance of a patient, may result in the partial overgrowth of the retention arms by the palatal mucosa (Figure 2c) of the retention arms by the palatal mucosa.

Furthermore, tipping and the resulting extrusion of the posterior teeth have been observed as a consequence of insufficient appliance rigidity and a screw located close to the occlusal plane. The bite opening caused by this can have negative consequences, especially for dolichofacial

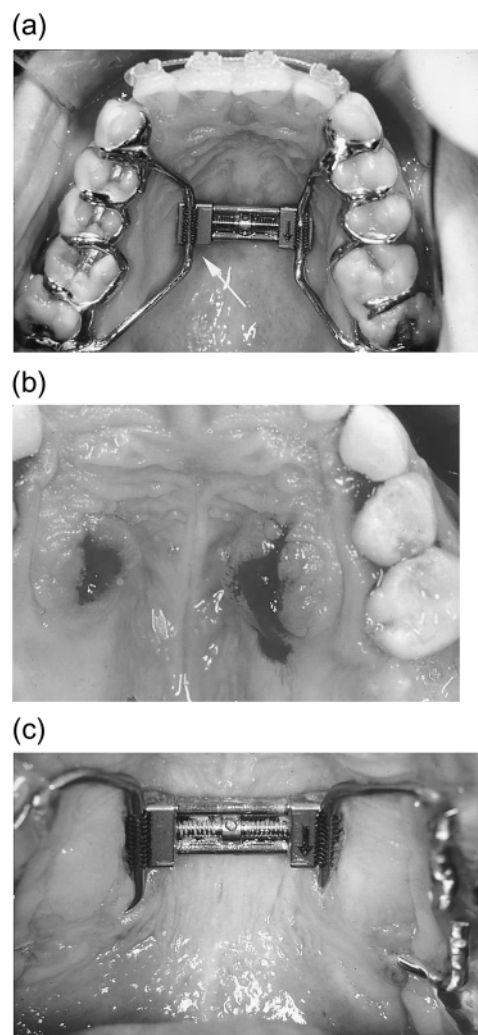


Figure 2 Pressure points during rapid maxillary expansion (a) and pressure ulcers after appliance removal due to plastic deformation of the retention arms (b); yielding of retention arms combined with long non-attendance of a patient, resulting in partial overgrowth of the retention arms by the palatal mucosa (c).

patients (Byrum, 1971; Murray and Cleall, 1971; Alpern and Yurosko, 1988; Adkins *et al.*, 1990; Lamparski *et al.*, 2003).

The occurrence of these unwanted side-effects provided the motivation for this pilot study. It was the intention to analyse an obvious clinical weak point and to subject the retention arms of various Hyrax-type expansion screws to technical material analysis. More specifically, the aims were to determine how retention arms react to stress, to identify the physical parameters that play a role in this, and to determine the relationship of these parameters with one another.

Materials and methods

The retention arms from 16 commercially available four-arm RME expansion screws with variable expansion

capacities (Figure 3, Table 1) and from an eight-arm screw (Figure 4, Table 2) were subjected to a three-point bending test. The examination was based on the ÖNORM EN ISO 7438: 2005 11 01 (Austrian Standards Institute, 2005a) and ÖNORM EN ISO 7500-1: 2005 02 01 (Austrian Standards Institute, 2005b) recommendations.

The retention arms of the expansion screws were formed of round wire. Fifteen were stainless steel (single arms) with a cross-sectional diameter of 1.48–1.49 mm. The eight-arm screw was a fortified version of the four-arm Tiger Dental screw and contained four doubled retention arms. For one of the screws (Dentaurum-Titan-Hyrax-14/12), the retention arms were made of pure titanium with a cross-sectional diameter of 1.68 mm.

For testing, three retention arms of 15 single-arm screws and two of one single-arm screw were separated from the screws and individually positioned with their straight run square to the trial block of a universal testing machine (Autograph, AG-G 100kN; Shimadzu Austria Company, Korneuburg, Austria) with software from the Messphysik Materials Testing Company, Fürstenfeld, Austria.

A distance of 15 mm between the specimen supports was used (corresponding to approximately the average length of a retention arm from the screw body to the splint or band). The radius of the centric-reversed bending mandrel was 1.5 mm (Figure 5).

A loading rate of 2.0 mm/minute was selected. Bending was determined without contact by measuring the transverse movement of the test machine by means of a connected video extensometer (OS 65D Camera, Mintron Company, Taipei, Taiwan) with software from the Messphysik Materials Testing Company (Figure 6).

The machine has an accuracy class of 1, i.e. the indication error determined was a maximum of ±1 per cent with respect to a calibrated measurement norm. The requirements for the testing of metallic materials were thus met.

The following parameters were determined:

F_{max} = maximum force = the maximum force that can be applied to the specimen (newton). This parameter

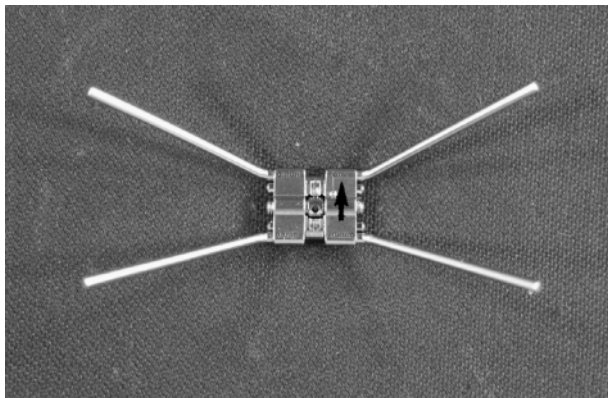


Figure 3 Standard four-arm rapid maxillary expansion screw.

Table 1 Bending test results of single retention arms of rapid maxillary expansion screws.

Description (expansion screws)	Max. Exp. (mm)	Ret. arm Ø M (mm)	Group	F_{max} (N)	$\sigma_{F_{max}}$ (N/mm ²)	$F_{0.1}$ mm (N)	$\sigma_{F_{0.1}}$ mm (N/mm ²)	$F_{0.2}$ mm (N)	$\sigma_{F_{0.2}}$ mm (N/mm ²)	f_{max} (mm)
SUPERscrewSUPERspring Co, Highwood, USA; the SUPERscrew ($n = 3$); size 12 + 12 mm	12	1.49 SS	1	288.0	3325.9	220.9	2550.7	254.5	2938.5	2.05
SUPERscrewSUPERspring Co; the SUPERscrew ($n = 3$); size 16 + 18 mm	18	1.49 SS		287.0	3314.7	218.3	2520.5	255.6	2951.4	1.86
Tiger Dental, Bregenz, Austria; four-arm screw ($n = 3$)	11	1.48 SS	2	273.9	3227.7	215.7	2541.2	239.9	2827.0	2.17
Forestadent, Pforzheim, Germany; anatomic expander; type 'S' ($n = 3$); order no. = 167-1326	10	1.48 SS	2	227.2	2676.6	158.6	1886.5	187.7	2211.5	2.21
Forestadent, Palatinalplitschraube, type 'N' ($n = 3$), order no. = 167-1633	12	1.48 SS		226.9	2673.9	156.7	1846.5	186.2	2193.9	2.20
Forestadent, memory anatomic expander; type 'S' ($n = 3$), order no. = A167-M1326	8	1.48 SS		225.3	2654.7	160.1	1886.1	188.8	2224.7	2.17
Leone, Firenze, Italy; rapid expander ($n = 2$); order no. = A 0620-11	11	1.48 SS	3	216.8	2554.5	150.0	1767.4	174.1	2051.0	2.47
Leone, rapid expander with telescopic guides ($n = 3$), order no. = A 2620-07	7	1.48 SS		173.7	2046.7	125.0	1472.8	142.5	1679.5	2.45
Leone Ragno fan type, rapid expander ($n = 3$), order no. = A 0625-09	9	1.48 SS		169.6	1998.7	130.2	1534.4	147.4	1736.6	2.15
Lewa, Remchingen, Germany; special screws for maxillary expansion ($n = 3$); order no. = 1114/10	5	1.48 SS	4	204.0	2403.3	141.4	1666.3	166.4	1960.9	2.46
Lewa, special screws for maxillary expansion ($n = 3$); order no. = 1114/22	18	1.48 SS		199.2	2347.1	143.7	1692.7	164.9	1943.3	2.18
Scheu, Iserlohn, Germany; Vector 620 ($n = 3$); special screws for GNE; order no. = 2526	11	1.48 SS	5	192.1	2263.5	138.4	1631.1	157.8	1859.7	2.41
Scheu, Vector 600 ($n = 3$); special screws for GNE; order no. = 2524	9	1.48 SS		184.8	2177.1	130.6	1538.8	151.1	1780.6	2.63
Dentaurum, Ispringen, Germany; Hyrax Maxi-12; GNE screw ($n = 3$); order no. = 602-822-10	12	1.48 SS	6	173.0	2038.8	125.7	1481.6	144.0	1697.1	2.47
Dentaurum, Hyrax Mini-7, GNE screw ($n = 3$), order no. = 602-816-10	7	1.48 SS		171.7	2023.5	124.3	1464.0	140.3	1653.1	2.50
Dentaurum, Titan-Hyrax-14/12 ($n = 3$), special screws for GNE; order no. = 602-810-10	12	1.68 Ti		145.9	1175.3	103.7	835.6	119.4	961.9	2.65

Max. Exp., maximal expansion; Ret. arm, retention arm; SS, stainless steel; Ti, Titan; M, Material; n , number of tested retention arms; GNE, Gaumennahterweiterung.

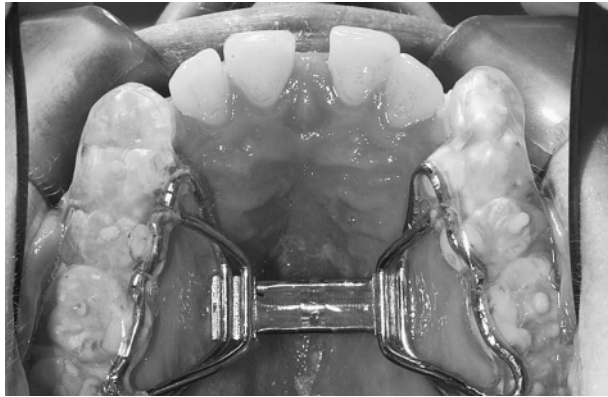


Figure 4 Eight-arm rapid maxillary expansion screw (four double arms) with a splint device in a 27-year-old patient when more rigid retention arms are required.

is dependent on the cross-sectional area, the sample geometry (=cross-sectional form), and the quality of the material.

$f_{F_{max}}$ = measure of ductility (deformability). This corresponds to the total bending (=elastic and plastic; millimetre) of the specimen at the time of F_{max} .

$F_{0.1\text{ mm}} (0.2\text{ mm})$ = the force required to permanently bend the specimen by 0.1 mm (0.2 mm; newton).

$\sigma_{F_{max}}$ = maximum bending stress = material stability = the bending stress induced in the specimen by the application of F_{max} [newton/square millimetre = Megapascal (MPa)]. This parameter is independent of sample geometry and only provides information regarding the material quality (=dependent on the composition of the alloy and on the method of preparation).

$\sigma_{F_{0.1\text{ mm}} (0.2\text{ mm})}$ = the bending stress induced in the specimen by application of $F_{0.1\text{ mm}} (0.2\text{ mm})$ (newton/square millimetre = MPa).

The arithmetic mean was determined for each of the parameters by measuring the retention arms of each screw type. These findings were subsequently used to compare and analyse the properties of the different screws. The double arms of the newly developed eight-arm expansion screw were tested for comparison with the single retention arms of the conventional four-arm RME screws. This involved the determination of the force values F_{max} , $F_{0.1\text{ mm}}$, and $F_{0.2\text{ mm}}$ for one- and two-sided, terminally welded double arms using the standardized bending test described above. Because this test specimen does not consist of an homogeneous unit, it was not possible to calculate the bending stress from F_{max} as for the homogeneous single arms. All tests were carried out by one author (MP) under the same conditions and immediately after each other. The error of the method for every screw was found by determining the relative repeatability ([Austrian Standards Institute, 2005b](#)). The values were between 0.29 and 2.40 per cent.

Table 2 Bending test results of double retention arms from an expansion screw

Description (expansion screws)	Max. Exp. (mm)	Ret. arm Ø (mm)	M	Group	F_{max} (N)	$\sigma_{F_{max}}$ (N/mm ²)	$F_{0.1\text{ mm}}$ (N)	$\sigma_{F_{0.1\text{ mm}}}$ (N/mm ²)	$F_{0.2\text{ mm}}$ (N)	$\sigma_{F_{0.2\text{ mm}}}$ (N/mm ²)	$f_{F_{max}}$ (mm)
Tiger Dental; eight-arm screw ($n = 3$); double arm, welded at one end (=experimental)	—	2×1.48	SS	Double-arm screw	694.0	—	453.7	—	516.4	—	3.76
Tiger Dental; eight-arm screw ($n = 2$); double arm, welded at both ends (=original)	11	2×1.48	SS		927.0	—	578.4	—	634.3	—	3.37

Max. Exp., maximal expansion; Ret. arm, retention arm; SS, stainless steel; M, Material; n , number of tested retention arms

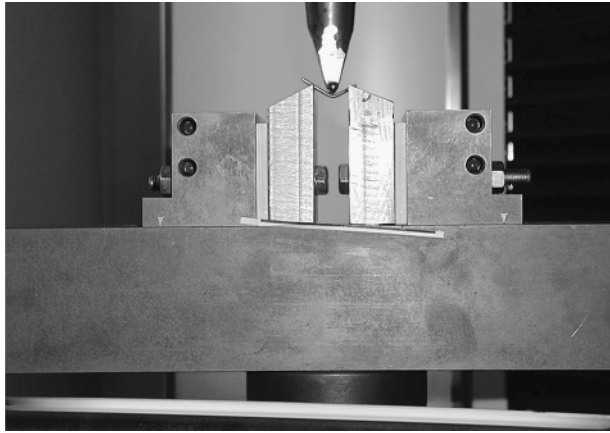


Figure 5 Three-point bending test: retention arm on the trial block of the Shimadzu universal testing machine and centric-reversed bending mandrel.



Figure 6 Experimental setup with video extensometer and Shimadzu Autograph.

Results

Based on the above findings, the tested retention arms were divided into six product groups with approximately comparable results (Table 1).

The results for group 1, which comprised three screw types, revealed high force values ($F_{\max} = 273.9\text{--}288.0$ N; $F_{0.1\text{ mm}} = 215.7\text{--}220.9$ N; $F_{0.2\text{ mm}} = 239.9\text{--}255.6$ N) as well as corresponding material stability (high stress values: $\sigma_{F_{\max}} = 3227.7\text{--}3325.9$ N/mm²; $\sigma_{0.1\text{ mm}} = 2520.5\text{--}2550.7$ N/mm²; $\sigma_{0.2\text{ mm}} = 2827.0\text{--}2951.4$ N/mm²). In other words, the dimensions of the arms and the material quality corresponded with each other to a very high degree.

In group 2, which also comprised three types of screws, the force values ($F_{\max} = 225.3\text{--}227.2$ N; $F_{0.1\text{ mm}} = 156.7\text{--}160.1$ N; $F_{0.2\text{ mm}} = 186.2\text{--}188.8$ N) and the material stability ($\sigma_{F_{\max}} = 2654.7\text{--}2676.6$ N/mm²; $\sigma_{0.1\text{ mm}} = 1846.5\text{--}1886.1$ N/mm²; $\sigma_{0.2\text{ mm}} = 2193.9\text{--}2224.7$ N/mm²) were of a relatively high level and corresponded with each other.

The difference between the lowest values of group 1 and the highest values of group 2 was greater than the differences between all other group pairs.

The force values ($F_{\max} = 169.6\text{--}216.8$ N; $F_{0.1\text{ mm}} = 125.0\text{--}150.0$ N; $F_{0.2\text{ mm}} = 142.5\text{--}174.1$ N) and stress measurements ($\sigma_{F_{\max}} = 1998.7\text{--}2554.5$ N/mm²; $\sigma_{0.1\text{ mm}} = 1472.8\text{--}1767.4$ N/mm²; $\sigma_{0.2\text{ mm}} = 1679.5\text{--}2051.0$ N/mm²) in group 3 were smaller and more broadly distributed. A concurrence between corresponding parameters was also observed.

In groups 4 ($F_{\max} = 199.2\text{--}204.0$ N; $F_{0.1\text{ mm}} = 141.4\text{--}143.7$ N; $F_{0.2\text{ mm}} = 164.9\text{--}166.4$ N; $\sigma_{F_{\max}} = 2347.1\text{--}2403.3$ N/mm²; $\sigma_{0.1\text{ mm}} = 1666.3\text{--}1692.7$ N/mm²; $\sigma_{0.2\text{ mm}} = 1943.3\text{--}1960.9$ N/mm²) and 5 ($F_{\max} = 184.8\text{--}192.1$ N; $F_{0.1\text{ mm}} = 130.6\text{--}138.4$ N; $F_{0.2\text{ mm}} = 151.1\text{--}157.8$ N; $\sigma_{F_{\max}} = 2177.1\text{--}2263.5$ N/mm²; $\sigma_{0.1\text{ mm}} = 1538.8\text{--}1631.1$ N/mm²; $\sigma_{0.2\text{ mm}} = 1780.6\text{--}1859.7$ N/mm²), which contained two screw types, respectively, the force and stress values were lower, tightly distributed, and correlated with one another.

Two screw types in group 6 displayed somewhat lower and relatively closely distributed force ($F_{\max} = 171.7\text{--}173.0$ N; $F_{0.1\text{ mm}} = 124.3\text{--}125.7$ N; $F_{0.2\text{ mm}} = 140.3\text{--}144.0$ N) and material stability values ($\sigma_{F_{\max}} = 2023.5\text{--}2038.8$ N/mm²; $\sigma_{0.1\text{ mm}} = 1464.0\text{--}1481.6$ N/mm²; $\sigma_{0.2\text{ mm}} = 1653.1\text{--}1697.1$ N/mm²) and again were correlated with each other.

A third screw type occupied a special position in this group: its retention arms had a larger diameter than all the others (1.68 mm) and were made of titanium. The force values were lower in comparison with those of the other products ($F_{\max} = 145.9$ N; $F_{0.1\text{ mm}} = 103.7$ N; $F_{0.2\text{ mm}} = 119.4$ N). A similar result was obtained for material stability ($\sigma_{F_{\max}} = 1175.3$ N/mm²; $\sigma_{0.1\text{ mm}} = 835.6$ N/mm²; $\sigma_{0.2\text{ mm}} = 961.9$ N/mm²).

For comparison with the product groups described above consisting of screws with four single retention arms, double retention arms from a newly developed eight-arm screw were tested for the force parameters F_{\max} , $F_{0.1\text{ mm}}$, and $F_{0.2\text{ mm}}$ (Table 2).

This specimen was made of two single arms of the screw type ranked third in group 1 according to the force and stress values. The bending test was carried out in the same manner as for the other screws, with two arms positioned perpendicularly on top of each other in a special fixture. For the first test, the double arms were welded experimentally at the end of one side and for the second they were welded at both ends in a manner similar to the original commercially available device. Three of the one-end-welded and two of the both-ends-welded double retention arms were tested and the mean value calculated for each parameter.

For the double arms welded at one end, the F_{\max} value of 694.0 N was 2.53 times greater than the values of the corresponding single-arm screws. The $F_{0.1\text{ mm}}$ (453.7 N) and the $F_{0.2\text{ mm}}$ (516.4 N) values were around 2.1 times greater than those of the single arm. For double arms welded at both ends, force values of $F_{\max} = 927.0$ N, $F_{0.1\text{ mm}} = 578.4$ N and $F_{0.2\text{ mm}} = 634.3$ N were obtained. In contrast to the

data for the corresponding individual arms, F_{\max} was 3.38 times higher and both $F_{0.1 \text{ mm}}$ and $F_{0.2 \text{ mm}}$ more than 2.6 times higher.

A further parameter examined for all retention arms was ductility, $f_{F_{\max}}$, which corresponds to total bending (=elastic and plastic) of the specimen at the time point when F_{\max} is reached. For this measurement, mean values of 1.86–2.17 and 2.17–2.21 mm were obtained for the groups 1 and 2, respectively. The mean values of groups 1, 3 (2.15–2.47 mm), and 4 (2.18–2.46 mm) were more broadly distributed, while those of groups 2, 5 (2.41–2.63 mm), and 6 (2.47–2.50 mm) were closer to each other.

The titanium screw type (group 6) with retention arms with a greater diameter (1.68 mm) than the comparison products, exhibited the highest $f_{F_{\max}}$ value (2.65 mm) of all single arms tested. This might be accounted for by the greater ductility of the more elastic metal titanium compared with the stiffer stainless steel.

Statistical analysis of the relationship between the parameters F_{\max} (=maximum force) and ductility $f_{F_{\max}}$ (=bending at F_{\max}) using Pearson correlation coefficient revealed a significant indirect correlation of $r = -0.780$ with an associated confidence level of $P < 0.001$. The relationship between the ductility $f_{F_{\max}}$ and the maximum bending stress $\sigma_{F_{\max}}$ (=material stability) also displayed a significant indirect correlation of $r = -0.778$ with an associated confidence level of $P < 0.001$.

For the double arms that were experimentally welded together only at one end and consequently were movable with respect to one another during the bending test, total bending of 3.76 mm was measured while applying a high F_{\max} of 694.0 N. In comparison with the corresponding single arms with their F_{\max} of 273.9 N and ductility of 2.17 mm, the double arms welded at only one end exhibited only a 73.27 per cent increase in ductility in spite of a 2.53 times greater F_{\max} . For the double arms welded at both ends in a manner similar to the original screw and therefore located in a stiff, unmovable position with respect to each other, total bending of only 3.37 mm was found with an extremely high applied F_{\max} of 927.0 N. Compared with the corresponding single arms, this represents an increase in ductility of only 55.29 per cent despite the application of a 3.38 times greater F_{\max} .

Discussion

According to the equation $\sigma_B = \frac{M_B}{W_B}$, there is a relationship between σ_B [=bending stress (newton/square millimetre)], M_B [=maximum bending moment with centric load (newton millimetre)], and W_B [=moment of resistance (cubic millimetre)].

The maximum bending moment M_B is equal to $\frac{F \times l}{4}$, where F represents any determined force (newton), for instance, F_{\max} or $F_{0.1(0.2) \text{ mm}}$ and l (millimetre) denotes the

distance between the specimen supports on the test block (for the present analysis: 15 mm).

For the tested round wires, the moment of resistance W_B corresponds to $\frac{\Pi \times d^3}{32}$, where d is the cross-sectional diameter of the specimen (Gieck, 1969).

It follows from these relationships that increased force values [F_{\max} and $F_{0.1(0.2) \text{ mm}}$] can be obtained by an increased retention arm diameter, d , as well as by an increased bending stress, σ_B —which again is dependent on the material quality (composition of the alloy and preparation procedure;

$$F = \frac{\Pi \times d^3 \times \sigma_B}{8 \times l}.$$

Despite the fact that in this study the retention arms of 15 of the tested expansion screws had identical cross-sectional diameters and consisted of stainless steel, considerable differences in loading values were found. The maximum force for the strongest retention arm exceeded that of the weakest by 69.81 per cent. For the maximum bending stress, the equivalent relationship was 66.40 per cent, for $F_{0.1 \text{ mm}}$ 77.71 per cent, for $\sigma_{0.1 \text{ mm}}$ 74.22 per cent, for $F_{0.2 \text{ mm}}$ 82.18 per cent, and for $\sigma_{0.2 \text{ mm}}$ 78.53 per cent.

Since the cross-sectional area and sample geometry (round wire) in this part of the various specimens were always the same, this discrepancy in the results concerning the force and stress values can only be explained by variations in material quality.

Another possible way to increase force values is with the use of double arms that are welded to one another. With samples that are the same length, double retention arms that are welded at both ends (as in the eight-arm screw) reach 3.38 times higher force maxima ($F_{\max} = 927.0 \text{ N}$) with only a 55.29 per cent higher ductility ($f_{F_{\max}} = 3.37 \text{ mm}$) compared with the corresponding individual arms ($F_{\max} = 273.9 \text{ N}$; $f_{F_{\max}} = 2.17 \text{ mm}$) and 3.21 times higher force maxima than the best result from among all the other analysed single retention arms ($F_{\max} = 288.0 \text{ N}$).

A particular causality underlies the relationship between ductility, maximum force, and maximum bending tension (=material stability). The significant indirect relationship between the parameters, ductility $f_{F_{\max}}$ and maximum force F_{\max} , as well as that between ductility and maximum bending stress (material stability) $\sigma_{F_{\max}}$, means that deformability (ductility) diminishes with increasing material stability (maximum bending stress) and also with increasing maximum force. The measurements revealed that the mean ductility of the most rigid single steel retention arms (group 1) was 22.77 per cent lower than that of the least rigid arms (group 6).

The same phenomenon has been observed between different types of metal, for instance, between the more rigid stainless steel that exhibits a lower degree of deformability compared with the more elastic titanium (Arens and Hansis, 1996). This material is ideally suited for use in patients who are allergic to components of stainless steel alloys. In terms

of its physical properties, this metal has a low elasticity modulus ($E = 105.000 \text{ N/mm}^2$; Bantleon, 1989) and when subjected to a similar stress level has approximately twice the elasticity of stainless steel. The greater stiffness of stainless steel ($E = 210.000 \text{ N/mm}^2$; Bantleon, 1989) in comparison with titanium is, on the other hand, associated with a lower level of deformability (ductility; Arens and Hansis, 1996). The results of the bending test can be accounted for by the lower stiffness, though better ductility of pure titanium as compared with stainless steel.

Conclusions

1. Despite having the same cross-sectional diameter, the single retention arms of all tested stainless steel expansion screws displayed variable loading capacities (force, stress, and deformation parameters) when subjected to three-point bending.
2. The larger dimension retention arms of the titanium expansion screw displayed the lowest force and stress loading capacities but the greatest deformability.
3. The eight-arm screw (four double arms) exhibited the highest force values.
4. The relevance of the variation between the tested retention arms lies in the clinical demand. During the pre-pubertal period, the rigidity of retention arms is not as important as in the following periods of increasing interdigitation and ossification of the median palatal suture.

Funding

Medical University Clinic of Graz.

Acknowledgements

The authors would like to express their thanks to I. Mischak for statistical analysis.

References

- Adkins M D, Nanda R S, Currier G F 1990 Arch perimeter changes on rapid palatal expansion. *American Journal of Orthodontics and Dentofacial Orthopedics* 97: 194–199
- Alpern M C, Yurosko J J 1988 Forcierte Gaumennahterweiterung bei Erwachsenen mit und ohne chirurgische Eingriffe. *Informationen aus Orthodontie und Kieferorthopädie* 15: 437–453
- Arens S, Hansis M 1996 Titanium implants in accident surgery—when are they necessary? *Langenbecks Archiv für Chirurgie. Supplement. Kongressband Deutsche Gesellschaft für Chirurgie* 113: 938–940
- Asanza S, Cisneros G J, Nieberg L G 1997 Comparison of Hyrax and bonded expansion appliances. *Angle Orthodontist* 67: 15–22
- Austrian Standards Institute. 2005a ÖNORM EN ISO 7438: 2005 11 01 metallic materials—bend test. Technical Standards Committee 021 Steel & Iron, Vienna
- Austrian Standards Institute. 2005b ÖNORM EN ISO 7500-1: 2005 02 01 metallic materials—verification of static uniaxial testing machines—part 1: tension/compression testing machines—verification and calibration of the force-measuring system. Technical Standards Committee 021 Steel & Iron, Vienna
- Bantleon H P 1989 Die Simulation von Zahnbewegungen in Abhängigkeit von Drehmoment und Kraft unter Anwendung einer dafür entwickelten elektronischen Messapparatur. Thesis, Universität Graz
- Byrum A G Jr 1971 Evaluation of anterior/posterior and vertical skeletal change vs. dental change in rapid palatal expansion cases as studied by lateral cephalograms. *American Journal of Orthodontics* 60: 419 (Abstract)
- Fürthauer U, Droschl H 1981 Die Gaumennahtsprengung als interzeptive Maßnahme. *Stomatologie* 78: 165–168
- Gieck K 1969 Technische Formelsammlung. 22 deutsche Auflage: Festigkeit Biegung/p.3; Festigkeit Träger/p.4. K. Gieck, Heilbronn
- Haas A J 1965 The treatment of the maxillary deficiency by opening the midpalatal suture. *Angle Orthodontist* 35: 200–217
- Lamparski D G Jr, Rinchuse D J, Close J M, Sciote J J 2003 Comparison of skeletal and dental changes between 2-point and 4-point rapid palatal expanders. *American Journal of Orthodontics and Dentofacial Orthopedics* 123: 321–328
- Murray J M, Cleall J F 1971 Early tissue response to rapid maxillary expansion in the midpalatal suture of the rhesus monkey. *Journal of Dental Research* 50: 1654–1660
- Spolyar J L 1984 The design, fabrication, and use of a full-coverage bonded rapid maxillary expansion appliance. *American Journal of Orthodontics* 86: 136–145
- Timms D J 1986 Forcierte Gaumennahterweiterung. Quintessence GmbH, Berlin
- Winsauer H, Richter M 1990 Forcierte Gaumennahterweiterung mit geklebten Kappenschiene-Geräten. *Stomatologie* 87: 387–394