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Effects of the zygoma anchorage system on canine retraction

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SUMMARY The aim of this study was to compare the effects of the Gjessing (PG) retraction spring used with and without the zygoma anchorage system (ZAS) on canine retraction.

Thirty patients, with an Angle Class I or Class II malocclusion, whose upper first premolars were scheduled for extraction, were divided into two equal groups. Group 1 comprised maximum anchorage cases (nine females and six males with a mean age of 16 years 8 months) in which the ZAS was used to improve posterior anchorage and the PG retraction springs for canine retraction. Moderate anchorage cases (10 females and 5 males with a mean age of 15 years 5 month) were included in group 2 and canine retraction was achieved using only PG retraction springs. Study models and lateral cephalometric radiographs obtained at the initial and final stages of canine retraction were used for comparison of the groups to determine the effects of zygoma anchorage on canine retraction. All measurements were evaluated statistically using a Student's *t*-test, 2 × 2 repeated measures analysis of variance, Bonferroni-adjusted *t*-test, and Mann–Whitney *U* and Wilcoxon tests according to the normality of the distribution of the variables.

Mesial crown movement of the molars was 0.63 mm ($P < 0.05$) in group 1 and 1.50 mm ($P < 0.001$) in group 2. There was a statistically significant difference ($P < 0.05$) between the groups. No significant difference was observed between the groups for the rate of canine retraction or sagittal and vertical movement of the canines.

The ZAS is a reliable and successful anchorage reinforcement method for canine retraction in extraction cases.

Introduction

The canines have an important role in oral function and aesthetics. Their unique position connects the anterior and posterior segments of the dental arch and makes their orthodontic movement of clinical importance, especially in premolar extraction cases.

In edgewise mechanics, orthodontic tooth movement during space closure can be achieved through two types of mechanics. The first is frictional mechanics in which the canine slides distally, guided by a continuous wire. The second, frictionless, involves closing loops fabricated either on full or sectional archwires. The teeth move due to activation of the wire loop, which can be designed to provide a low load/deflection curve and a controlled moment to force ratio (Boester and Johnston, 1974; Burstone and Koening, 1976; Gjessing, 1985, 1994; Ziegler and Ingervall, 1989; Staggers and Germane, 1991).

Frictional systems for canine retraction have potential disadvantages, such as delay in tooth movement. Increasing the force to overcome this delay causes loss of anchorage, tipping of canines, and extrusion of incisors (Andreasen and Johnson, 1967; Burstone and Koening, 1976; Gjessing, 1985; Ziegler and Ingervall, 1989).

It has been claimed that it is possible to apply a more controlled force with frictionless systems during canine distalization (Boester and Johnston, 1974; Burstone and Koening, 1976; Gjessing, 1985, 1994; Ziegler and Ingervall, 1989; Staggers and Germane, 1991). Various retraction mechanics have been devised to overcome undesired movements, such as canine tipping, rotation, and anchorage loss, in sectional arch mechanics. It has been reported that the PG retraction arch (Gjessing, 1985, 1994) provides the desired biomechanical properties for retraction of the canines in a controlled manner.

Anchorage control is an important aspect of orthodontic therapy. During orthodontic treatment, the teeth are exposed to forces and moments, which generate reciprocal forces of the same magnitude but in opposite directions. Maintaining the position of the posterior teeth has always been a concern during canine retraction, mainly in cases where maximum anchorage is needed. When extraoral devices are employed, anchorage can be stable but depends on the patient's cooperation. An advantage of appliances using intraorally derived anchorage is that they do not require patient cooperation. However, intraoral anchorage is unstable and has some undesirable side-effects, including protrusion, extrusion, and tipping of anchorage teeth. Using orthodontic implants can prevent these disadvantages (Gray *et al.*, 1995; Park *et al.*, 2004; Chen *et al.*, 2005; Thiruvenkatachari *et al.*, 2006; Kuroda *et al.*, 2007).

A number of studies have been reported in the literature in which screw type implants, palatal implants, and zygoma anchorage systems (ZAS) have been used to increase the anchorage of posterior teeth, or as direct anchorage for the retraction of canines or *en masse* retraction of the six anterior teeth (Wehrbein *et al.*, 1999; Park *et al.*, 2001, 2005; Bae *et al.*, 2002; De Clerck *et al.*, 2002; Miyawaki *et al.*, 2003; Hayashi *et al.*, 2004; Park and Kwon, 2004; Crismani *et al.*, 2005; Erverdi and Acar, 2005; Herman *et al.*, 2006; Iino *et al.*, 2006; Thiruvenkatachari *et al.*, 2006).

The purpose of this study was to compare the effects of the PG retraction spring used with and without anchorage reinforcement using the ZAS for canine retraction.

Subjects and method

Nineteen females and 11 males at the completion of craniofacial growth, or at the post-pubertal development stages according to their hand-wrist radiographs, with an Angle Class I or Class II malocclusion, whose upper first premolars were scheduled for extraction, were included in the study. All patients and parents were informed of the experimental protocols and signed an informed consent form. The research had previously been approved by the Ethics Committee of Başkent University.

The patients were divided into two groups of 15 subjects. The first group comprised maximum anchorage cases (nine females and six males aged between 12 years 8 months and 21 years 9 months, respectively, mean 16 years 8 months). Zygomatic anchors (Orthodontic Bone Anchor; Surgitec, Bruges, Belgium) were placed in the zygomatic buttress regions, while PG retraction springs were used for canine retraction. Group 2 consisted of moderate anchorage cases (10 females and 5 males aged between 11 years 4 months and 21 years 5 months, respectively, mean 15 years 5 months) in whom PG retraction springs were used for canine retraction without ZAS (Table 1). Anchorage requirement was determined according to the subject's arch length discrepancies, incisor positions, molar relationships, and soft tissue profiles during initial treatment planning.

Table 1 Descriptive values of chronological age, treatment time, and retraction rate parameters and comparison of mean values of group 1 [zygoma anchorage system (ZAS) + Gjessing (PG) spring] and group 2 (PG spring). $\bar{x}$, arithmetic mean; $s_{\bar{x}}$, standard error.

	Group 1	Group 2	*P*
	$\bar{x} \pm s_{\bar{x}}$	$\bar{x} \pm s_{\bar{x}}$	
Chronological age (years)	16.63 ± 0.74	15.40 ± 0.89	ns
Retraction duration (months)	4.71 ± 0.22	4.08 ± 0.30	ns
Retraction rate (mm/month)	1.20 ± 0.13	1.64 ± 0.26	ns

ns: Not significant.

Subsequent to extraction of the upper first premolars, 0.018 inch slot Roth brackets (Ormco Corporation, Orange, California, USA) and molar bands (GAC International Inc., Bohemia, New York, USA) were applied. Levelling of the canines, second premolars, and first molars was achieved using 0.016, 0.016 × 0.016, and 0.016 × 0.022 inch nickel titanium arches sequentially. The anchors were then placed in left and right zygomatic buttress regions to improve posterior anchorage in group 1. The maxillary canines were then retracted with PG retraction springs in both groups in accordance with the recommendation of Gjessing (1985).

The ZAS consists of a three-holed titanium miniplate and a round bar connecting the plate with the fixation unit (De Clerck *et al.*, 2002). A 1 cm vertical incision was made at the inferior crest of the zygomaticomaxillary buttress, which extended to the border of the mobile and attached gingivae, under local infiltrative anaesthesia without sedation. A mucoperiosteal flap was elevated and the cortical bone surface at the implant side was exposed. After the zygoma anchor was adapted to the curvature of the bone crest, three holes were drilled and the anchor was fixed with three self-tapping miniscrews (2.0 mm diameter and 6 mm long; Figure 1a) covered with mucoperiosteum and sutured (Figure 1b). Care was taken to position the round bar and fixation unit of the zygoma plate on the attached gingiva. The patients were prescribed antibiotics and were advised to use analgesics and an antiseptic mouthwash for 1 week and to practice good oral hygiene during the healing period.

One week after surgery, the sutures were removed and the fixation unit of the plates and gingival tube of the molar bands were fixed with a 0.016 × 0.022 inch stainless steel wire (Figure 1c). At the same appointment, 0.016 × 0.022 inch stainless steel PG retraction springs were placed for canine retraction. For activation, the two sections of the double helix were separated 1 mm from each other by pulling the wire distal to the molar tube and bending it over (Gjessing, 1985). The springs were activated every 4 weeks during space closure.

Treatment was also carried out on the lower arches of the patients in both groups. The lower premolars were extracted in 10 patients in group 1 and in 14 in group 2. No Class II or Class III mechanics were used during the canine retraction period.

Study models and standardized lateral cephalograms were obtained for each patient at the initial and final stages of canine retraction. All radiographs were traced on a light box in a dark room using a 0.3 mm lead pencil. Model measurements were undertaken directly on the models using a digital calliper (Mitutoyo, Kanagawa, Japan) accurate to 0.01 mm. All model and cephalometric measurements were undertaken by the same investigator (AÇ).

Twenty-nine measurements (12 angular and 17 linear) were made on the cephalometric tracings (Figure 2a, b, and c). The palatal plane (PP) and a vertical plane constructed from PNS to the palatal plane (VR) were used to measure the dentoalveolar parameters. The retraction rate of the

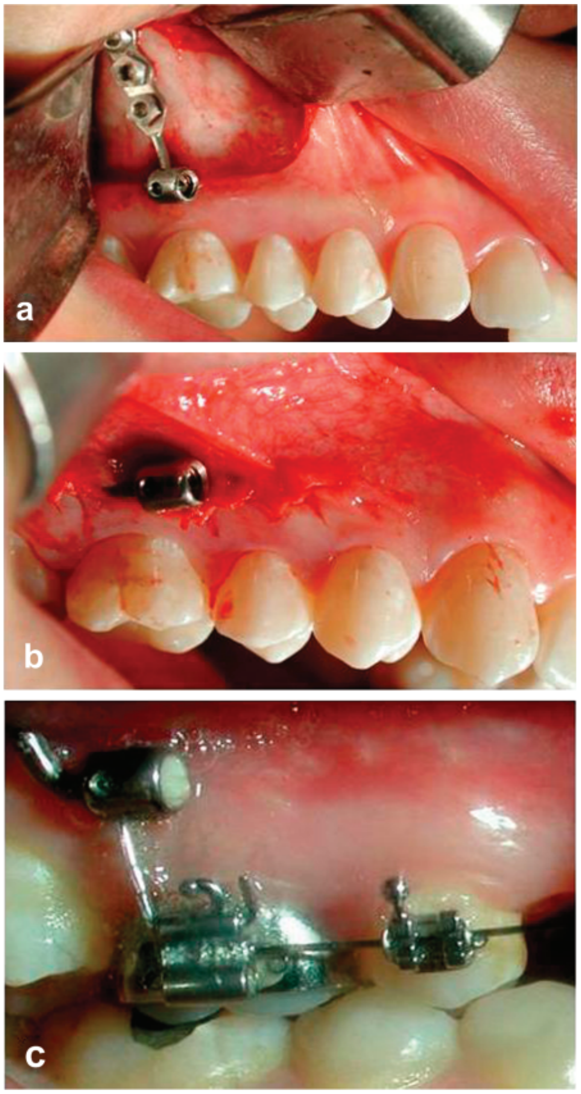

Figure 1 (a) The zygoma anchor adapted and fixed to the zygomaticomaxillary bone crest. (b) Covered with mucoperiosteum and sutured. (c) Fixation unit of the plates and gingival tube of the molar bands with a 0.016 × 0.022 inch stainless steel wire.

canines was also calculated as the ratio between the change in the U3i–VR measurement and the duration of retraction. Five measurements were made on the study models (Figure 2d). Rotation of the canines was determined by subtracting the distance between the distal contact points of the upper canines from the distance between their mesial contact points. Rotation of molars was again determined by subtraction of the distance between the distobuccal cusp tips of upper first molar crowns from the distance between their mesiobuccal cusp tips (Figure 2d).

Statistical analysis

Statistical analysis was performed using the Statistical Package for Social Sciences Version 13.0 (SPSS Inc., Chicago, Illinois, USA). The normality of the distribution of the variables was verified using Shapiro–Wilk test and the homogeneities of the group variances by Levene's test. The group means of age and retraction time parameters were compared with a Student's *t*-test, while the group means of variables, including repeated measures, normally distributed with homogeneous variances were compared by 2 × 2 repeated measures analysis of variance and Bonferroni-adjusted *t*-test. For comparison of the group means of variables not normally distributed, a Mann–Whitney *U*-test was used for the independent groups and a Wilcoxon test for the dependent groups. The results were determined as the mean ± the standard error (SE) of the mean, median, minimum, and maximum values. $P < 0.05$ was considered to be statistically significant.

Method error

Four weeks after the first measurements, the tracings and measurements were repeated by the same investigator on 20 lateral cephalograms and dental models of 10 randomly selected patients. To assess the reliability of the measurements, the intraclass correlation coefficients (r) were calculated for each variable. Intraclass correlation coefficients ranged from 0.93 to 1.00.

Results

The mean treatment duration for canine retraction was 4.71 ± 0.22 months in group 1 and 4.08 ± 0.30 months in group 2. The difference between the groups was not significant (Table 1).

The rate of canine retraction was 1.20 ± 0.13 and 1.64 ± 0.26 mm/month in groups 1 and 2, respectively. There was no significant difference between the groups (Table 1).

Comparisons of the pre-retraction measurements of the two groups are given in Table 2. U6a–VR distance ($P < 0.001$), U1a–VR distance, U3a–VR distance, U6–PP angle ($P < 0.01$), U1i–VR distance, and U3i–VR distance ($P < 0.05$) showed statistically significant differences, while all other measurements were similar, showing homogeneity of the groups.

Changes in each group as a result of canine retraction and comparison of the changes in the two groups are given in Table 3. All skeletal parameters remained unchanged in both groups ($P > 0.05$).

When dentoalveolar changes due to canine retraction were examined, SN–OP angle showed a significant increase in group 1 ($P < 0.05$), and a significant difference was found between the groups ($P < 0.01$). In both groups, the upper and lower incisors were retracted and retroclined and the upper incisors were significantly extruded. The increase in overbite was found to be significant in both groups ($P < 0.01$).

The upper canines showed distal tipping ($P < 0.001$), distal crown movement ($P < 0.001$), and intrusion ($P < 0.05$) in both groups.

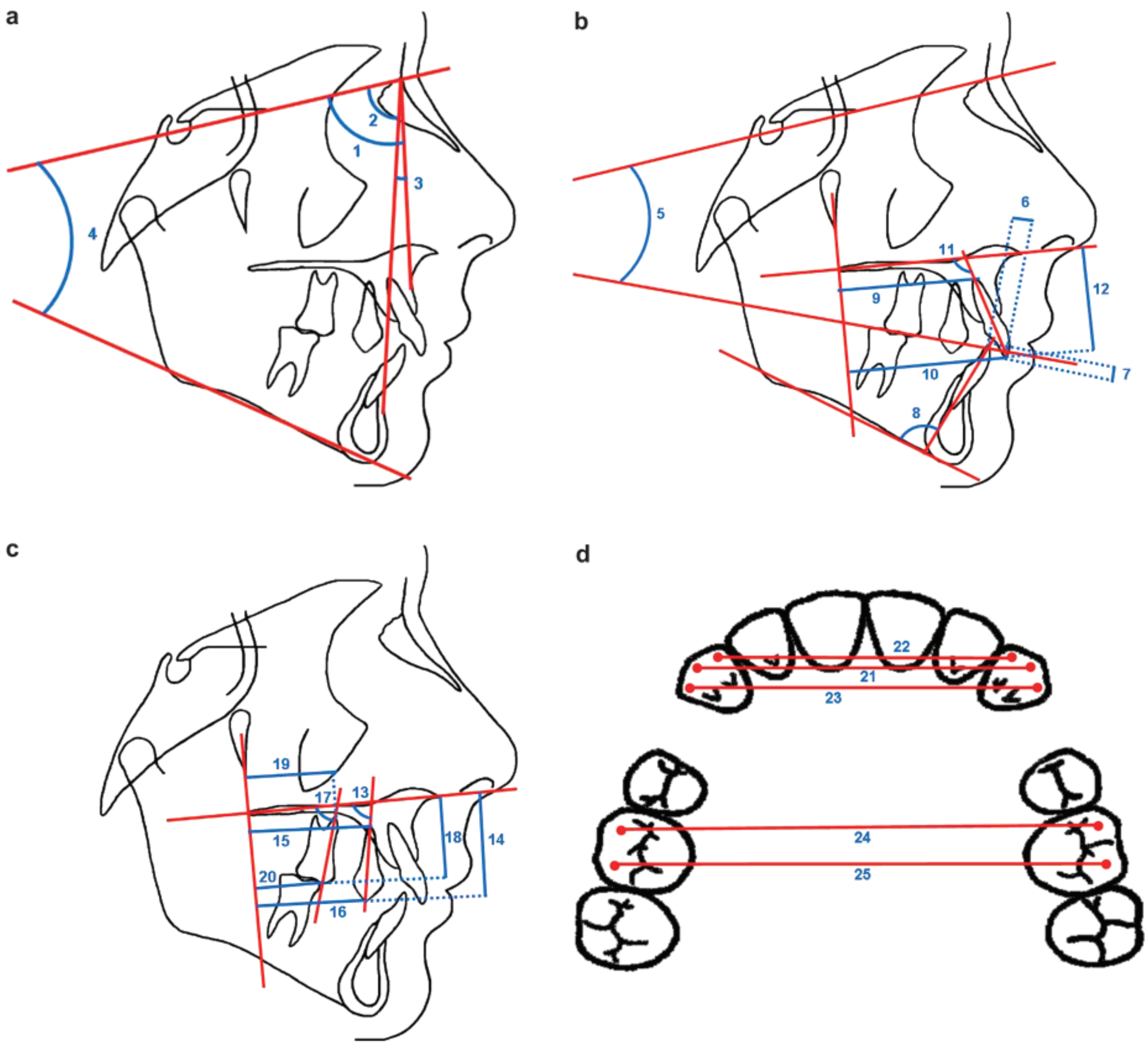

Figure 2 Measurements used in this study. Skeletal (a) 1: SNA, 2: SNB, 3: ANB, 4: GoGn–SN; (b) dentoalveolar—5: SN–OP, 6: overjet, 7: overbite, 8: IMPA, 9: U1a–VR (mm), 10: U1i–VR (mm), 11: U1–PP (degree), 12: U1–PP (mm); (c) 13: U3–PP (degree), 14: U3–PP (mm), 15: U3a–VR (mm), 16: U3i–VR (mm), 17: U6–PP (degree), 18: U6–PP (mm), 19: U6a–VR (mm), 20: U6c–VR (mm); and (d) study model—21: intercanine, 22: U3m, 23: U3d, 24: intermolar, 25: U6db, 26: canine rotation (22–23), 27: molar rotation (24–25).

While the upper first molars showed 1 degree of mesial tipping ($P < 0.01$) and 0.63 mm of mesial crown movement ($P < 0.05$) in group 1, 1.5 mm of mesial crown ($P < 0.001$) and 1.1 mm of root ($P < 0.05$) movement was found in group 2. There was a statistically significant difference between the groups for mesial crown movement of the upper molars ($P < 0.05$).

When the dental models were evaluated for both groups, a statistically significant decrease was found for intermolar distance ($P < 0.01$) and the distance between the distobuccal cusp tips of the right and left first molars ($P < 0.001$) and a statistically significant increase for canine rotation ($P < 0.001$). Intercanine distance ($P < 0.05$), the distance between the mesial contact points ($P < 0.01$) and the distance between the distal contact points of the right and left canines ($P < 0.05$) and molar rotation ($P < 0.01$), showed a significant increase in group 1. Statistically significant differences were found between the groups for intercanine distance ($P < 0.05$), the distance between the mesial contact points of the right and left canines ($P < 0.01$) and molar rotation ($P < 0.05$).

Intraoral lateral views of patients from groups 1 and 2 are shown in Figure 3.

Discussion

Anchorage control is an important factor affecting the treatment results during fixed orthodontic treatment with extractions. Anchorage loss can lead to unsuccessful treatment outcomes by increasing the difficulty of correction of the malocclusion in the antero-posterior direction (Geron *et al.*, 2003; Erverdi *et al.*, 2004; Chen *et al.*, 2005; Thiruvenkatachari *et al.*, 2006). In order to increase

Table 2 Pre-retraction descriptive and comparative statistics of measurements in group 1 [zygoma anchorage system (ZAS) + Gjessing (PG) spring] and group 2 (PG spring). $\bar{x}$, arithmetic mean; $s_{\bar{x}}$, standard error; Min, minimum; Max, maximum.

	Group 1			Group 2			P
	$\bar{x} \pm s_{\bar{x}}$	Median	Min–Max	$\bar{x} \pm s_{\bar{x}}$	Median	Min–Max	
Skeletal							
SNA	80.63 ± 0.84	81.50	76 to 85	80.96 ± 1.06	80.50	75 to 88.50	ns
SNB	74.93 ± 0.69	75	69 to 80	76.30 ± 1	77	69.50 to 83	ns
ANB	5.70 ± 0.74	5	1 to 10	4.66 ± 0.48	4	2 to 8.50	ns
GoGn–SN	34.50 ± 1.68	36	22 to 43	36.73 ± 1.55	35	25 to 47	ns
Dentoalveolar							
SN–OP	15.53 ± 1.13	17	9 to 22	17.30 ± 1.04	18	11 to 24	ns
Overjet	5.80 ± 0.76	5.50	2 to 12	5.33 ± 0.61	5	2.50 to 9	ns
Overbite	2.53 ± 0.76	3	−3 to 7	1.76 ± 0.63	3	−3 to 5	ns
IMPA	94.90 ± 1.71	93	86 to 106	91.43 ± 1.85	89	78.50 to 104	ns
U1a–VR (mm)	37.63 ± 0.90	37	30.50 to 45	41.33 ± 0.67	41	36 to 46	**
U1i–VR (mm)	46.46 ± 1.39	46	37 to 58.50	50.66 ± 0.87	50	45 to 57	*
U1–PP (degree)	110.63 ± 2.80	111	90 to 131	111.20 ± 1.50	109	102 to 121	ns
U1–PP (mm)	30.43 ± 0.98	30.50	21 to 36.50	31.06 ± 0.72	31	26 to 38	ns
U3–PP (degree)	101.36 ± 1.37	102.50	93 to 111	100.93 ± 1.39	101	91 to 109	ns
U3–PP (mm)	29.13 ± 0.88	29	22.50 to 36.50	28.90 ± 0.75	28.50	25 to 37	ns
U3a–VR (mm)	32.93 ± 0.94	32	29.50 to 43	36.26 ± 0.54	36	33 to 40	**
U3i–VR (mm)	37.90 ± 1.05	38.50	32.50 to 47	41.10 ± 0.63	40	37.50 to 47	*
U6–PP (degree)	87.60 ± 1.03	88	81 to 97	82.90 ± 1.06	83	75 to 90	**
U6–PP (mm)	24.66 ± 0.60	24.50	20 to 29	24.43 ± 0.65	24.50	21 to 32	ns
U6a–VR (mm)	18.33 ± 0.88	18.50	13 to 24.50	22.16 ± 0.58	22.50	17.50 to 26	***
U6c–VR (mm)	17.53 ± 0.91	17.50	11.50 to 24.50	19.76 ± 0.46	20	16 to 23.50	ns
Study model							
Intercanine	33.63 ± 0.58	33	31 to 38.50	34.56 ± 0.78	35	28.50 to 40.50	ns
U3m	28.93 ± 0.61	28.50	25.50 to 33.50	30.10 ± 0.69	31	24 to 34.50	ns
U3d	35.90 ± 0.50	36	33.50 to 40.50	36.66 ± 0.64	36.50	33 to 42	ns
Canine rotation	−6.96 ± 0.40	−7	−9.50 to −4.50	−6.56 ± 0.36	−6.5	−9 to −3.50	ns
Intermolar	49.33 ± 0.78	49.50	42.50 to 54	50.20 ± 0.63	50	45.50 to 55.50	ns
U6db	51.70 ± 0.83	51.50	44.50 to 57	52.23 ± 0.66	52	48 to 58.50	ns
Molar rotation	−2.36 ± 0.23	−2.50	−3.50 to −0.50	−2.03 ± 0.19	−2	−4 to −1	ns

ns, not significant. $*P < 0.05$, $**P < 0.01$, $***P < 0.001$.

maxillary posterior anchorage, transpalatal arches, Nance holding appliances, or extraoral appliances have been used (Hart *et al.*, 1969; Baker *et al.*, 1972; Perez *et al.*, 1980; McLaughlin and Bennett, 1991; Rajcich and Sadowsky, 1997; Chen *et al.*, 2005; Crismani *et al.*, 2005; Prabhu and Cousley, 2006). However, anchorage loss can be seen with intraoral anchorage devices due to insufficient stability, and poor patient cooperation can be a major drawback of extraoral appliances (Egolf *et al.*, 1990; Gray *et al.*, 1995; Keleș *et al.*, 2003).

Screw type implants can be used both indirectly for anchorage reinforcement and directly for canine retraction (Bae *et al.*, 2002; Herman *et al.*, 2006; Thiruvenkatachari *et al.*, 2006) or *en masse* retraction (Park *et al.*, 2001, 2005; Park and Kwon, 2004) with frictional mechanics. Microscrews have advantages such as simple implantation procedures, high patient tolerance, early loading, and low cost. On the other hand, there are potential risks of damaging adjacent teeth during tooth movement when implanted between roots. In addition, since maxillary buccal cortical bone is thinner than mandibular bone, maxillary implants show a lower success rate than mandibular implants (Miyawaki *et al.*, 2003).

The ZAS is usually used as direct anchorage for space closure. Having an ideal bone structure, the inferior border of the zygomaticomaxillary process is a suitable site for implantation and is situated away from the upper molar roots. In addition, a miniplate fixed to the bone with three screws provides sufficient anchorage for immediate loading (De Clerck *et al.*, 2002; Erverdi and Acar, 2005; Iino *et al.*, 2006).

When the parameters regarding the maxillary canines were evaluated, it was seen that the type of tooth movement was controlled tipping and the crowns of canines were

Table 3 Changes in groups 1 [zygoma anchorage system (ZAS) + Gjessing (PG) spring] and 2 (PG spring), significance of changes in each group and statistical comparison of changes in groups. $\bar{D}$, mean difference; S_D, standard error; Min, minimum difference; Max, maximum difference.

	Group 1				Group 2				*P*
	$\bar{D} \pm s_D$	Median	Min–Max	*P*	$\bar{D} \pm s_D$	Median	Min–Max	*P*	
Skeletal									
SNA	0 ± 0	0	0 to 0	ns	0,03 ± 0,03	0	0 to 0.50	ns	ns
SNB	−0.10 ± 0.07	0	−1 to 0	ns	0.10 ± 0.09	0	−0.50 to 1	ns	ns
ANB	0.10 ± 0.07	0	0 to −1	ns	−0.07 ± 0.07	0	−0.50 to 0.50	ns	ns
GoGn–SN	0.33 ± 0.22	0	−1 to 2.50	ns	−0.20 ± 0.28	0	−2.50 to 1	ns	ns
Dentoalveolar									
SN–OP	0.57 ± 0.24	0.50	−1 to 2	*	−0.40 ± 0.24	0	−2.50 to 1	ns	**
Overjet	−0.47 ± 0.36	−0.50	−3 to 2.50	ns	−0.33 ± 0.23	−0.50	−1.50 to 1.50	ns	ns
Overbite	0.83 ± 0.17	1	−0.50 to 1.50	**	1.07 ± 0.31	1	−1 to 3.5	**	ns
IMPA	−1.20 ± 0.56	−1	−5 to 3	***	−2.17 ± 0.64	−2	−6.50 to 1.50	***	ns
U1a–VR (mm)	0 ± 0.18	0	−1 to 1.50	ns	0.40 ± 0.19	0.50	−1 to 1.50	ns	ns
U1i–VR (mm)	−1.10 ± 0.27	−1	−3 to 0.50	**	−0.80 ± 0.13	−1	−1.50 to 0	***	ns
U1–PP (degree)	−3.17 ± 0.74	−4	−7 to 2	**	−2.10 ± 0.40	−2	−5 to 1	***	ns
U1–PP (mm)	0.43 ± 0.12	0.50	−0.50 to 1	**	0.13 ± 0.14	0	−1 to 1	**	ns
U3–PP (degree)	−11.93 ± 1.36	−11.50	−21.50 to −2	***	−13.03 ± 1.53	−12	−22.50 to 0	***	ns
U3–PP (mm)	−0.57 ± 0.29	−0.50	−2.50 to 1	*	−0.37 ± 0.25	−0.50	−2 to 1.50	*	ns
U3a–VR (mm)	−0.40 ± 0.27	−0.50	−2.50 to 1	ns	0 ± 0.29	0	−2 to 2	ns	ns
U3i–VR (mm)	−5.57 ± 0.55	−5.50	−9 to 0	***	−6.20 ± 0.67	−6	−12.50 to 2.50	***	ns
U6–PP (degree)	1 ± 0.25	1	0 to 3	**	0.97 ± 0.57	1	−3 to 5.50	ns	ns
U6–PP (mm)	−0.33 ± 0.17	0	−2 to 0.50	ns	0.27 ± 0.20	0	−1 to 1.50	ns	ns
U6a–VR (mm)	0.27 ± 0.19	0.50	−1 to 1.50	ns	1.10 ± 0.43	1	1 to 4.50	*	ns
U6c–VR (mm)	0.63 ± 0.19	1	−1 to 1.50	*	1.50 ± 0.28	1.50	0.50 to −3.50	***	*
Study model									
Intercanine	5.50 ± 0.64	6	1.50 to 9.50	*	3.43 ± 0.51	3.50	1 to 7.50	ns	*
U3m	8.20 ± 0.54	8	5 to 12.50	**	5.70 ± 0.66	5.50	2.50 to 10	ns	**
U3d	1.93 ± 0.72	3.50	−3 to 5	*	0.33 ± 0.30	0	−1.50 to 2.50	ns	ns
Canine rotation	6.27 ± 0.49	6	4 to 9.50	***	5.37 ± 0.53	4.50	2.50 to 9.50	***	ns
Intermolar	−0.27 ± 0.27	0	−2.50 to 2.50	**	−1.23 ± 0.40	−1	−5 to 1	**	ns
U6db	−1.07 ± 0.39	−1	−4.50 to 2	***	−1.37 ± 0.44	−1	−6 to 1.50	***	ns
Molar rotation	0.80 ± 0.21	0.50	0 to 2.50	**	0.13 ± 0.13	0	−1 to 1	ns	*

ns, not significant. $*P < 0.05$, $**P < 0.01$, $***P < 0.001$.

tipped distally without any root movement. The amount of distal tipping was 11.93 degrees in group 1 and 13.03 degrees in group 2. Significant canine intrusion was also observed in both groups. No statistically significant difference was found regarding canine movement between the two groups. The amount of canine tipping observed was higher than in previous studies evaluating the effects of PG springs (Ziegler and Ingervall, 1989; Dinçer and İşcan, 1994; Dinçer *et al.*, 2000).

Eden and Waters (1994) demonstrated that the PG retraction spring tends to tip the canines distally during retraction unless the canine arm is gabled to approximately 45 degrees. It has been reported that the angle of the gable bend could decrease as a result of deformation, which may occur during insertion of the spring in the bracket slot. Besides any increase in the activation force can negate bodily movement of the canines (Caputo *et al.*, 1974; Burstone and Koening, 1976; Eden and Waters, 1994).

The rate of canine retraction was 1.20 ± 0.13 and 1.64 ± 0.26 mm/month in groups 1 and 2, respectively, demonstrating no significant intergroup difference. In previous studies examining the effects of the PG retraction arch, the canine retraction rate was reported as 0.85 mm/month by Dinçer and İşcan (1994), 0.92 mm/month by Dinçer *et al.* (2000), and 1.91 mm/month by Ziegler and Ingervall (1989).

The mean anchorage loss measured at the first molar crown was 0.63 mm in group 1 and 1.50 mm in group 2. The molar roots showed no significant movement in group 1, while the 1.10 mm of anchorage loss was significant in group 2. The difference between the groups was also significant. Even though the observed anchorage loss at the molar crowns was significant in group 1, movement of 0.63 mm

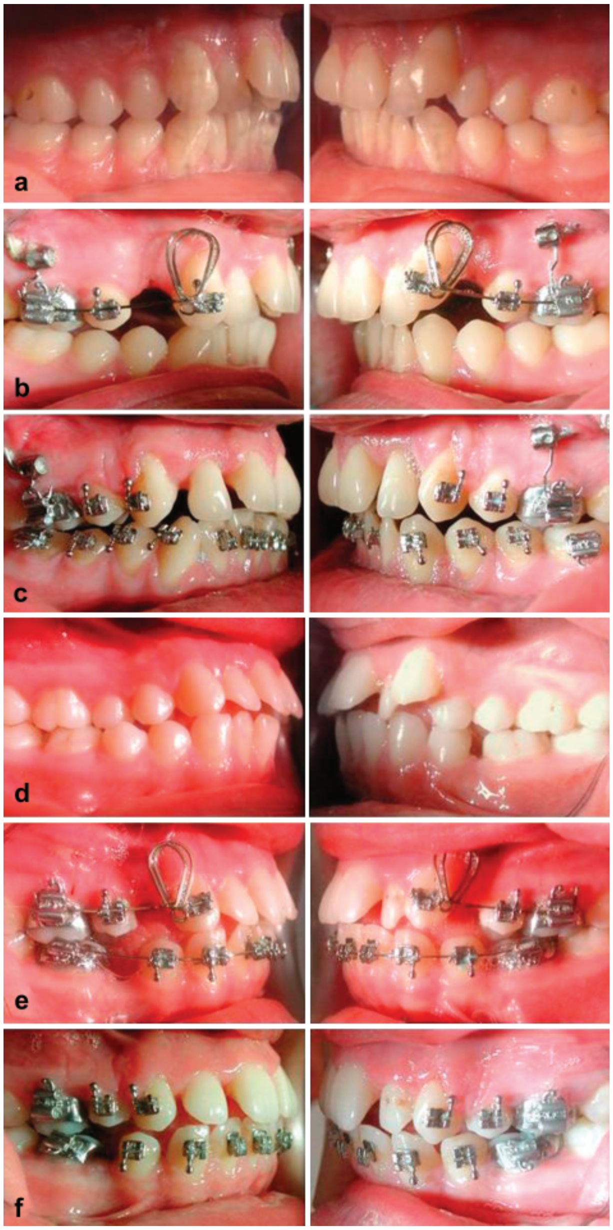

Figure 3 Pre-treatment (a), pre-retraction (b), and post-retraction (c) lateral intraoral views of a patient in group 1. Pre-treatment (d), pre-retraction (e), and post-retraction (f) lateral intraoral views of a patient in group 2.

could be considered clinically irrelevant as the width of the periodontal ligament is almost 0.5 mm.

Gjessing (1994) reported that against the β-moment formed by the PG retraction spring, anchorage loss can occur without side-effects, such as extrusion. The vertical force exerted by the β-moment at the posterior side of the PG retraction spring, neutralizes the extrusion force exerted by the α-moment (Figure 4). While 0.33 mm of molar intrusion was observed in group 1, group 2 demonstrated 0.27 mm of molar extrusion. The vertical movement of the molars was not statistically significant in either group.

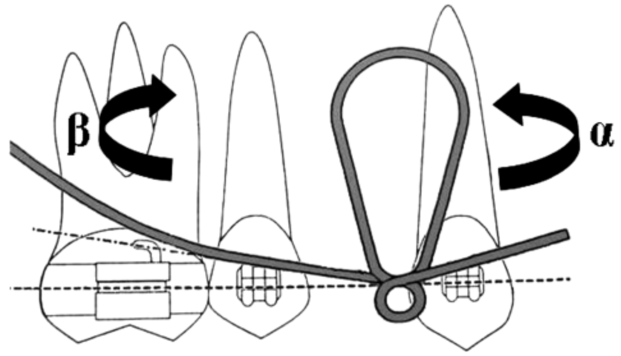

Figure 4 Diagram demonstrating the α- and β-moments of the Gjessing retraction spring.

In studies in which the PG retraction spring was used for canine retraction without any maxillary posterior anchorage reinforcement, the mean anchorage loss at the maxillary molars was reported as 1.50 mm by Dinçer *et al.* (2000) and 1.63 mm by Dinçer and İşcan (1994). These results are similar to the findings for group 2. Ziegler and Ingervall (1989) found 0.60 mm anchorage loss for the upper molars with the PG retraction spring applied together with a Goshgarian palatal arch and headgear. The present results in group 1 are similar to their findings.

The incisors were slightly retracted and retroclined due to transmission of the distal force applied to the canines by transseptal ligaments, in both groups (McCollum and Preston, 1980).

In group 1, there was a statistically significant increase in the occlusal plane angle, while a slight decrease, which was not significant, was found in group 2. The difference was significant between the two groups. This difference may be due to the significant extrusion of the incisors and intrusion of the molars in group 1, while extrusion of molars was evident in group 2.

A significant increase in overbite was found in both groups. This increase could be due to the slight retraction of the upper and lower incisors.

Different methods are advised for surveying study models. Maxillary palatal rugae are known to remain stable during development of the dentition and are used as fixed references to evaluate the positional changes of buccal teeth (Van der Linden, 1978). After marking the rugae, photocopies (Champagne, 1992) or photographs (Ziegler and Ingervall, 1989) of dental models are taken. On the other hand, measurements can also be carried out directly on the study models (Schütze *et al.*, 2007). In the present study, the direct measurement method was preferred as obtaining exact one-to-one photographs is difficult and photocopy images may be distorted due to different occlusal planes. Therefore, the amount of canine and molar rotation is reported in millimetres instead of degrees.

The study model measurements revealed that the distance between the right and left canine was increased. There are studies reporting an increase in intercanine width in extraction cases, reflecting distal movement of the canines into wider parts of the dental arch (Paquette *et al.*, 1992; Luppanappornlarp and Johnston, 1993; Bishara *et al.*, 1997; Kim and Gianelly, 2003). The reason for the more significant intercanine width increase in group 1 may be the different action of the anterior and posterior parts of the spring from the original spring design due to fixation of the molars with the ZAS. Also in agreement with Ziegler and Ingervall (1989), significant distopalatal rotation of the canines was found in both groups.

The distance between the mesiobuccal cusp tips of the right and left molars significantly decreased in group 2, while the distance between the distobuccal cusp tips of the right and left molars decreased in both groups. Distopalatal rotation of the molars was found to be significant in group 1. A decrease in intermolar distance has been reported in premolar extraction cases (Paquette *et al.*, 1992; Luppanappornlarp and Johnston, 1993; Bishara *et al.*, 1997; Kim and Gianelly, 2003). The antirotation bend in the PG retraction spring may be the cause of the distopalatal rotation of the molars. Again, the reason for the more significant molar rotation in group 1 may be the effects of the ZAS restricting mesial movement of the molar teeth.

In the present study, the ZAS was used as indirect anchorage to increase the anchorage of the maxillary first molars against the mesially directed force exerted by the PG retraction spring during canine retraction. The maxillary canines demonstrated significant distal tipping during retraction with the PG spring. The maxillary molar crowns showed statistically significant but minimal anchorage loss in both groups, while the molar roots moved mesially only in group 2. The two groups showed statistically significant intergroup differences regarding molar movement.

Clinically, when choosing a treatment method, the clinician has to consider available options. Placement of ZAS requires a procedure usually performed by a surgeon and has an extra cost. Therefore, ZAS may be an alternative for anchorage reinforcement of the PG spring only in extraction cases requiring maximum anchorage with no molar movement. Mini- or microscrews may, however, be more viable options for anchorage with their easier application and lower costs.

The ZAS was stable throughout the canine retraction period and was also used during retraction of the incisors in the second stage of treatment. Records at the end of treatment should be evaluated to determine stability.

Conclusions

The present study was conducted in order to examine the effects of the ZAS on maxillary canine retraction with the PG retraction spring. The following results were observed:

1. The PG retraction spring demonstrated significant distal tipping of the maxillary canines (11.93 degrees in group 1 and 13.03 degrees in group 2). There was no significant intergroup difference regarding movement and retraction rates of the canines.
2. The mean anchorage loss observed at the molar crowns was 0.63 mm in the ZAS supported group and 1.50 mm in group 2. The molar roots were stable in group 1, whereas 1.10 mm mesial movement was found in group 2. Molar movement showed statistically significant intergroup differences.

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