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Randomized Controlled Trial (RCT)

PASS versus MBT™ for evaluation of anchorage control in three-dimensional measurements: a randomized controlled trial

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Summary

Background: Growth and development might lead to anchorage loss during orthodontic treatment, such as the mesial drift of molars, the compensation characteristics of upper molars following mandibular growth, or the angulation of molars before treatment. Different anchorage reinforcement devices have been developed to prevent mechanical anchorage loss, but the anchorage loss resulting from physiological factors should also be taken into account.
Objective: To explore the efficacy of a new strategy to control physiologic anchorage compared with that of the conventional straight-wire appliance.
Trial design: Randomized controlled trial (RCT).
Methods: Participants of Han ethnicity were randomized into the physiologic anchorage spee-wire system (PASS) group or McLaughlin–Bennett–Trevisi (MBT™) straight-wire group by minimization random allocation. The eligibility criteria were patients with a Class I or II molar relationship, permanent dentition (11–35 years old), fixed appliances involving the extraction of at least two upper first premolars, and medium or maximum anchorage requirements. Pre-treatment and post-treatment dental casts were scanned into digital casts and measured using a blinded method. Mesial displacements of the upper first molars were considered as the primary outcome for evaluating anchorage control. Measurements were taken for subgroups based on age.
Results: Data from 60 participants were analysed. The baseline characteristics were not significantly different between groups. Mesial displacement of the upper first molar (in mm) was 2.96 ± 1.52 in the PASS group and 2.70 ± 1.66 in the MBT group ($P = 0.521$). The variation in incisor torque was −6.94 ± 6.35 degree in the PASS group and −11.76 ± 7.65 degree in the MBT group ($P = 0.010$). The incisor retraction (in mm) was 4.24 ± 1.99 and 5.67 ± 2.27 in the PASS and MBT groups, respectively ($P = 0.012$). Adverse effects were not documented in any patient.
Limitation: The study was a single-centre study.
Conclusions: Compared with the MBT group, the PASS group without additional anchorage devices could attain well anchorage control by considering the dentoalveolar compensation of anchor teeth.
Registration: This RCT was registered at the Chinese Clinical Trial Registry (Chictr.org.cn) ChiCTR-TRC-13003260.

Introduction

'Anchorage', as a mechanical concept, can be seen as 'resistance to a force' (1). During orthodontic treatment or in laboratory tests, anchorage can be seen as a biomechanical concept (i.e. a biologic response is involved in anchorage control).

Over time, different anchorage devices have been developed by leveraging the advantages of oral systems (2) or force systems. Several studies have focussed on the factors influencing anchorage loss to explore old hypotheses. Much attention has been paid to external factors while ignoring the important role of compensatory movement in anchorage loss.

'Dentoalveolar compensation' can occur if teeth that have suffered intercuspation apparently move in response to differential jaw growth after occlusion has been established. Tsourakis and Johnston (3) found a greater average mesial shift in the upper molars than in the lower molars independent of the initial terminal-plane relationship in Class II occlusion. White (4) demonstrated that the upper molars moved in the mesial direction almost twice as much as the lower molars moved. Kim *et al*. (5) compared the transition of molar relationships in different growth patterns. They revealed that the upper first molars might be under a greater influence than the lower molars. Their results were consistent with the idea that the mesial shift of the upper molars was a manifestation of dentoalveolar compensation due to mandibular growth (6,7). In terms of the upper molar movements relative to the basal bone, they would continue to grow forward and downward until approximately 25 years of age (8).

Orthodontists should attach importance to the mesial shift of the upper molars because of the compensatory movement along with mandibular growth that usually occurs among adolescents. Su *et al*. (9) found that boys showed a greater mesial inclination and movement of molars than girls. Xu *et al*. (10) found that in early adolescence, significant mesial movement of the upper molars occurs (especially in boys). Furthermore, Su *et al*. showed that the more distal the inclination of the upper molars before treatment, the greater was the mesial inclination at treatment completion (11).

It seems that the upper first molars (which are regarded as the anchor teeth) move forward irrespective of whether an orthodontic force is present. For non-treated populations, such mesial movement could be termed as 'physiologic shift'. However, for patients with Class I or II malocclusion, this type of growth pattern would lead to anchorage loss and could be termed as 'physiologic anchorage loss'.

The first stage of orthodontic treatment using a conventional straight-wire method involves the alignment and levelling of teeth. If the upper molar brackets are in a mesial inclination relative to the inclination of the upper molar, when the first nickel–titanium (NiTi) wire is engaged, the upper molars will experience a contra-rotated moment (12). This moment eliminates the natural-anchorage reserve of the upper molars that occurs with distal inclination before treatment. When McLaughlin, Bennett, and Trevisi were developing their MBT™ system, they claimed that the canine laceback should be used in the initial stage to control the canine crown position (13). Nevertheless, this strategy might increase the risk of anchorage loss.

Specific objectives or hypotheses

Prevention of physiologic anchorage loss in the initial stage of orthodontic treatment is important for patients (1) who need anchorage control and (2) with potential mandibular growth. Therefore, we aimed to explore the efficacy of prevention for upper molar dentoalveolar compensation by the physiological anchorage spee-wire system (PASS) without auxiliary anchorage devices compared with the MBT method. The null hypotheses tested were that there are no differences between the PASS and MBT methods.

Materials and methods

Trial design and any changes after trial commencement

This was a two-arm, parallel randomized controlled trial (RCT) with an allocation ratio of 1:1. The Biomedical Ethics Committee of the School and Hospital of Stomatology, Peking University (Beijing, China) approved the protocol of this RCT (PKUSSIRB-2013050). Written informed consent was obtained from all patients.

Participants, eligibility criteria, and setting

Participants were recruited at the Orthodontic Department, School and Hospital of Stomatology, Peking University, from June 2013 to July 2014. The inclusion criteria were patients (1) of Han ethnicity, (2) with a Class I or II molar relationship, (3) with permanent dentition (11–35 years old), (4) with fixed-appliance treatment, (5) who had two upper first premolars or four bimaxillary first premolars extracted, and (6) with medium- or maximum-anchorage requirements. Participants with the characteristics below were considered as the maximum anchorage requirements: crowding +2 × overjet >11 mm (14), U1/L1 angle <115 degree with a chief complaint of 'convex profile', or overjet >5 mm with an almost complete Class II molar relationship. Participants with the characteristics below were considered as the minimum anchorage requirements: overjet <5mm, mild overbite (upper teeth overlap 1/3–1/2 lower teeth), crowding <4mm, and with an acceptable profile. The medium anchorage requirements are the other than these two. Three orthodontists were asked to judge the anchorage requirements for each recruited patient according to the criteria and the individual feature. The exclusion criteria were patients (1) who needed molar distalization to attain extra space; (2) had molars (except the third molars) extracted; (3) had a 'scissor bite' of molars; (4) had undergone orthodontic or surgical treatment; (5) had missing or impacted teeth (except the third molars); (6) had systemic diseases (including long-term administration of medication), severe periodontitis, or congenital craniofacial deformity and syndromes; or (7) smoked or abused alcohol.

Interventions

Participants in the PASS group were treated according to PASS (12). Multi-level low-friction anterior brackets with a 0.020-inch slot size and posterior brackets with a 0.022-inch slot size were used (Shinye, Hangzhou, Zhejiang, China). In addition, a cross-buccal tube (XBT) with a −25 degree auxiliary tube on the upper first molar buccal tube (Figure 1) was featured in the PASS appliance (15). The recommended archwire sequence was 0.014-inch NiTi, 0.016/0.018-inch NiTi, 0.016 × 0.020-inch NiTi, 0.018 × 0.025-inch NiTi, and 0.018 × 0.025-inch stainless steel. We required the premolar brackets and second molar buccal tubes to not be bonded until all of the anterior teeth had been levelled and aligned. Furthermore, the initial NiTi archwire for anterior levelling and alignment should be inserted in the −25 degree auxiliary tube in the upper arch. A 0.018-inch stainless-steel 'piggy back' archwire could be bent to assist correction of a deep overbite (if necessary) in aligning and levelling stage. Before the space closure, the 0.018-inch stainless-steel archwire with helical loops could be used to upright the anterior teeth to normal inclination if the participants had proclined teeth. All of the upper

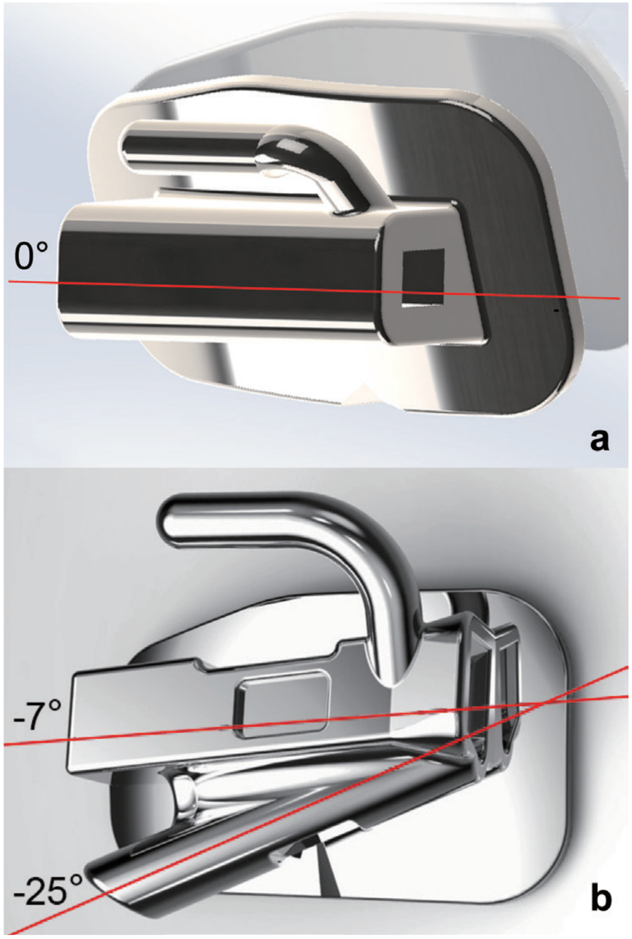

Figure 1. (a) Buccal tube of a straight-wire appliance (MBT prescription) with a 0-degree molar inclination prescription. (b) The XBT of a PASS appliance with a −7-degree inclination prescription and a −25-degree auxiliary tube. Reproduced from Chen *et al.* (15).

archwires that were inserted into the main tube were shaped in a normal spee curve, and no additional anchorage was mandatorily required.

Participants in the MBT group were treated according to the standard straight-wire method with 0.022-inch slot-size brackets and buccal tubes (13). Canine laceback ligatures were required for the levelling and aligning stages. For patients who needed maximum anchorage, a temporary anchorage device (TAD) could be used. In addition, other anchorage devices, such as the Nance holding arch, the transpalatal arch, or headgear facebow, could be used.

Three orthodontists experienced in both methods and who had been in practice for more than one decade performed all the treatments. All of the orthodontists were strictly trained before the trial began, and the possible ambiguity of the key operations, such as the bonding position of the appliance, the use of power chain or NiTi coils, and the instructions for the patients, was discussed and standardized. The follow-up visit interval after treatment was 4–6 weeks.

Outcomes (primary and secondary) and changes after RCT commencement

The primary outcome was the mesial displacement of the upper first molar after orthodontic treatment. Secondary outcomes were the sagittal displacement of the upper incisor; variation in the mesiodistal inclination of the upper canines and first molars; and torque variation of the upper incisors, canines, and first molars. The width between the upper bilateral canines and first molars was also measured (Table 1). The subgroup analysis was performed to detect the interaction effect between the interventions and the age groups.

Dental casts were taken before and after treatment. All dental casts were imaged by a three-dimensional (3D) laser scanner (R700; 3Shape, Copenhagen, Denmark). The digital files (saved in stereolithography interface format) were imported into reverse-engineering software (Rapidform 2006; Inus Technology, Seoul, Korea) and analysed. The pre-treatment and post-treatment maxillary digital casts for each participant were superimposed by palatal vault regional superimposition (16). The occlusal, sagittal, and coronal planes of each digital cast were constructed perpendicular to each other based on the post-treatment casts (Supplementary Figure S1).

According to the definition created by Andrew *et al.* (17), the occlusal point of the buccal axis (O) and the gingival point of the buccal axis (G) determined the facial axis of the clinical crown. Thus, point G and point O, as well as the mesial point (M) and the distal point (D), were defined as the landmarks for teeth measurements (Table 1). The local coordinate system for the targeted tooth was built according to the landmarks and global coordinate system (Figure 2). The post-treatment digital cast was measured first. Then, the landmarks on it were transferred to the pre-treatment cast to avoid errors in positioning (Supplementary Figure S2).

There were no changes in outcomes after RCT commencement.

Sample size calculation

The calculation of the sample size was based on the known variability of the mesial displacement of upper molars measured by Xu *et al.* (10). The power of the study was set at 80 per cent with an alpha significance level of 0.05 to detect the true mean difference of 1.75 mm (SD = 2.5 mm) in molar displacement between different methods. We found that 32 participants in each group were sufficient.

Randomization

Participants were randomized into the PASS group or MBT group at a 1:1 ratio using a random-allocation system with a minimization method (18). The gender, age groups, and anchorage requirements of patients were considered to be the variates before randomization. The allocation of the minimization method depended on the calculation of the sum of the difference in the distribution of the variates (the gender, age groups, and anchorage requirements). An example is shown in the supplementary materials to demonstrate the procedure of the minimization method (Supplementary Table S1).

Blinding

The appearance and treatment process were different between the two methods; thus, blinding was not possible. To minimize the risk of bias, the assessor performing the measurements and conducting the analyses was blinded to the study protocol.

Statistical analyses

The means ± SD were calculated for the baseline and study data. Chi-square tests were used to detect differences in gender, age groups (11.0–17.9 years old was considered juvenile, higher values were considered adults), and anchorage requirements between the two groups.

Levene's test was used to assess the variances of measurements for normality. Independent sample *t*-tests were used to compare variations of measurements with normal distribution between the two groups. Welch's *t*-tests were used to compare variations of measurements with non-normal distribution between the two groups. We

Table 1. Definition of the reference landmarks and the three-dimensional measurements.

Reference landmarks (abbreviation)	*Definition*
Gingival point (G)	The gingival point of the buccal axis of the clinical crown.
Occlusal point (O)	The occlusal point of the buccal axis of the clinical crown, the cusp tip of the canine, or the midpoint of the incisal edge.
Mesial point (M)	The most mesial point of the central fissure on the occlusal surface; for canines, the mesial end of the segment, representing the maximum mesiodistal dimension from the occlusal view; for incisors, the mesial point of the incisal edge.
Distal point (D)	The most distal point of the central fissure on the occlusal surface; for canines, the distal end of the segment, representing the maximum mesiodistal dimension from the occlusal view; for incisors, the distal point of the incisal edge.
Measurements	*Definition (compared between pre- and post-treatment dental casts)*
Mesial displacement of molars (mm)	Absolute variation of distance from the occlusal point of the molar buccal axis to the coronal plane.
Incisor retraction (mm)	Absolute variation of distance from the midpoint of the incisal edge to the coronal plane.
Torque variation in incisors (°)	Variation of the upper incisor torque. Positive for labial inclination.
Mesiodistal inclination of molars (°)	Variation of the upper molar mesiodistal inclination. Positive for mesial inclination.
Vertical variation of incisors (mm)	Absolute variation of distance from the midpoint of incisal edge to occlusal plane. Positive for extrusion.
Vertical variation of molars (mm)	Absolute variation of distance from the occlusal point of the molar buccal axis to the occlusal plane. Positive for extrusion.
Torque variation in molars (°)	Variation of the upper molar torque. Positive for buccal inclination.
Mesiodistal inclination of canines (°)	Variation of the upper canine mesiodistal displacement between before and after treatment. Positive for mesial inclination.
Torque variation of canines (°)	Variation of the upper canine torque. Positive for buccal inclination.
Inter-canine width variation (mm)	Distance between the projection of bilateral canine cuspids on the occlusal plane.
Inter-molar width variation (mm)	Distance between the projection of the occlusal point of the bilateral molar buccal axis on the occlusal plane.

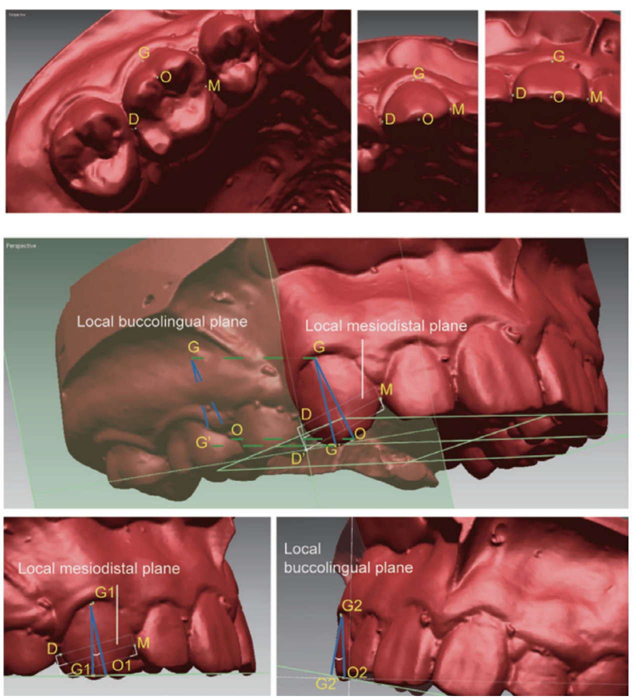

Figure 2. Construction of a local reference system. Taking the canine as an example, D′ was the projection of D on the occlusal plane. D, M, and D′ were used to construct the local mesiodistal plane, which was perpendicular to the occlusal plane. The buccolingual plane was constructed perpendicularly to the other two planes. G′ was the projection of G on the occlusal plane. The ∠OGG′ projected on the mesiodistal plane (∠O1G1G1′) was the mesiodistal inclination. The ∠OGG′ projected on the buccolingual plane (∠O2G2G2′) was the torque angulation.

used the General Linear Model to detect the interaction effect between the interventions and the subgroups based on age. Analyses were performed using SPSS v. 23 (IBM, Armonk, New York, USA). *P*-value less than 0.05 was considered significant.

Twenty sets of digital casts among samples were chosen randomly to access the repeatability of the 3D measurement. Both superimposition and measurements were repeated 1 month apart. The intraclass correlation coefficient showed a high level of line-spacing measurements (0.985) and angle measurements (0.886).

Results

Participant flow

Sixty-four participants were recruited. They were allocated randomly into the PASS group or MBT group (32 participants per group). Four participants were lost to follow-up for reasons beyond our control (Figure 3).

Baseline data

Gender, age groups, and anchorage requirements were recorded at baseline. Both groups showed a similar distribution in gender, age groups, and anchorage requirements. Because of the dropouts, the baseline characteristics of all participants in the trial, those lost to follow-up, and those remaining through the end were analysed (Table 2).

Numbers analysed for each outcome, estimation and precision, subgroup analyses

During treatments, 12 participants in the MBT group had TADs. Any auxiliary anchorage device was not used in the PASS group. The distribution of gender, age groups, and anchorage requirements were compared between the two groups before analyses. A significant difference was not found in the demographic data.

Little difference was found in the variation of the upper first molars and other target teeth except for the variation in the displacement of the upper incisors (Table 3). The mesial displacement of the upper first molar was 2.96 ± 1.52 mm in the PASS group and 2.70 ± 1.66 mm in the MBT group (t (58) = −0.646, P = 0.521). The retraction of the upper incisors was 4.24 ± 1.99 mm in the PASS group and 5.67 ± 2.27 mm in the MBT group (t (58) = 2.590, P = 0.012). Furthermore, the torque variation of the upper incisors was −6.94 ± 6.35 degree in the PASS group and −11.76 ± 7.65 degree in the MBT group (t (58) = −2.661, P = 0.010).

The General Linear Model found no interaction effect between the interventions and the age groups (F = 0.171, P = 0.681) (Figure 4).

Harms

Adverse events were not observed in any patient in either group.

Discussion

Main findings in the context of the existing evidence and interpretation

Re-consideration of anchorage preparation and differential moments

A clinically significant difference in the mesial displacement of molars was not found between the two groups. The variation was approximately less than 0.30 mm. In this respect, PASS without an auxiliary anchorage device seemed to result in identical anchorage control as that noted for the conventional method. This was the first study focusing on this new concept, so comparisons with other studies are not possible. The key concepts of the physiologic anchorage control system comprise two parts: initial anchorage preparation and the differential moment.

Anchorage preparation is held in high regard by Tweed *et al.* (19). Patients classified as 'Class II, division I' were usually treated to Class I bimaxillary protrusion because the teeth were too far forward compared with the basal bone. Tweed *et al.* emphasized the position of the lower incisors, but they also stated that the axial inclination of maxillary teeth should be rearranged to reduce resistance to distalization. They considered anchorage preparation to be the most important step in clinical orthodontics (20). This phase was achieved readily using the Tweed method. However, for the conventional straight-wire method, teeth would be aligned according to the prescription of the buccal tube or bracket (21). Hence, if the prescription of the buccal tube showed mesial inclined relative to the inclination of the upper first molar, the upper first molar might tip mesially, especially the initially distal-tipping molars, which could lead to early anchorage loss.

To attain anchorage preparation by NiTi archwires initially, the role of the differential moment was studied in the PASS (Figure 5). It was proposed first by Thomas Mulligan (22) and used through orthodontic treatments. Hart *et al.* (23) explored the efficacy of the differential moment in orthodontic cases. He generalized the concept of the differential moment as a 'partial strap-up' that involved only the anchor tooth and target tooth (canine and anterior teeth). Off-centre tip-back bending between the first molar and second premolar generated different magnitudes of the moment by regulating the length of the segment (24, 25). Larger moments dominated and were usually applied to the anchor teeth (e.g. molars). Similarly, in PASS, the concept of the differential moment was achieved by a −7 degree main (rectangular, 0.022 × 0.025 inch) tube and a −25 degree auxiliary (circular) tube. The second molar and second premolar were not involved initially either. When the first NiTi wire was engaged in the auxiliary tube, the first molar, because of its larger moment, would be maintained in its position or tip backwards (Supplementary Figure S3). Ko *et al.* (26) used the finite element analysis to detect the mechanical properties of XBT. They showed that the first molar would gain a backward force after the NiTi archwire had become engaged.

The differential moment would not create 'true' anchorage. However, the primary outcome did suggest that preventing the undesirable displacement of the anchor teeth might strengthen anchorage control. The retraction of the incisors and torque variation

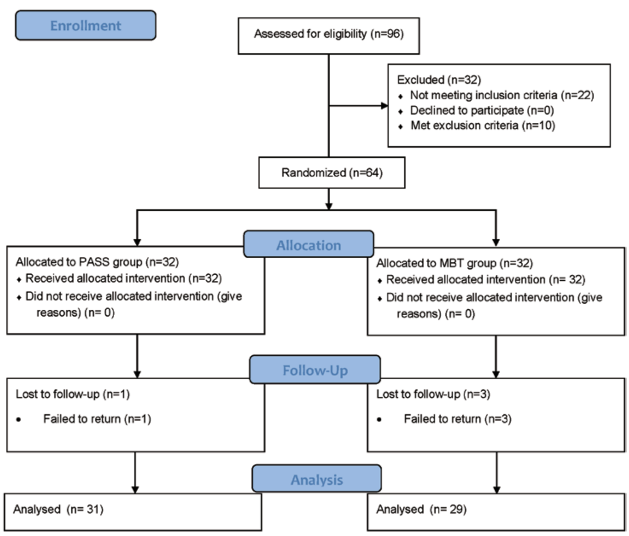

Figure 3. CONSORT flowchart.

Table 2. Baseline characteristics of all participants in the trial, those lost to follow-up, and those remaining through the end. PASS, physiologic anchorage spee-wire system; MBT™, McLaughlin–Bennett–Trevisi.

		All participants (N = 64)			Participants lost to follow-up (N = 4)		Remaining participants (N = 60)		
Baseline variable		PASS (n = 32)	MBT (n = 32)	P-value	PASS (n = 1)	MBT (n = 3)	PASS (n = 31)	MBT (n = 29)	P-value
Gender	Male	10	11	0.790	1	0	9	11	0.465
	Female	22	21		0	3	22	18	
Age group	Juvenile	22	22	1.000	0	3	22	19	0.650
	Adult	10	10		1	0	9	10	
Anchorage requirement	Maximum	11	11	1.000	1	0	10	11	0.645
	Medium	21	21		0	3	21	18	

Table 3. Comparisons of the measurements between PASS group and MBT group. SD, standard deviation; PASS, physiologic anchorage spee-wire system; MBT™, McLaughlin–Bennett–Trevisi; CI, confidence interval.

	PASS (*n* = 31)		MBT (*n* = 29)			
	M	SD	*M*	SD	95% CI	*P*-value
Mesial displacement of molars (mm)	2.96	1.52	2.70	1.66	−1.09, 0.56	0.521
Incisor retraction (mm)	4.24	1.99	5.67	2.27	0.32, 2.53	0.012
Torque variation of incisors (°)	−6.94	6.35	−11.76	7.65	−8.44, −1.19	0.010
Mesiodistal inclination of molars (°)	−0.90	5.46	−0.69	3.50	−2.17, 2.60	0.858
Vertical variation of incisors (mm)	1.77	1.77	1.34	1.99	−1.39, 0.55	0.385
Vertical variation of molars (mm)	0.33	0.92	−0.15	0.92	−0.95, 0.003	0.051
Torque variation of molars (°)	−1.33	7.54	0.79	4.36	−1.09, 5.34	0.191
Mesiodistal inclination of canines (°)	−0.56	7.69	−2.85	8.53	−6.48, 1.90	0.279
Torque variation of canines (°)	−6.40	6.69	−5.27	8.71	−2.86, 5.13	0.572
Bilateral canine width (mm)	0.79	2.37	0.67	1.95	−1.26, 1.00	0.823
Bilateral molar width (mm)	−2.08	1.84	−1.74	1.40	−0.51, 1.19	0.428

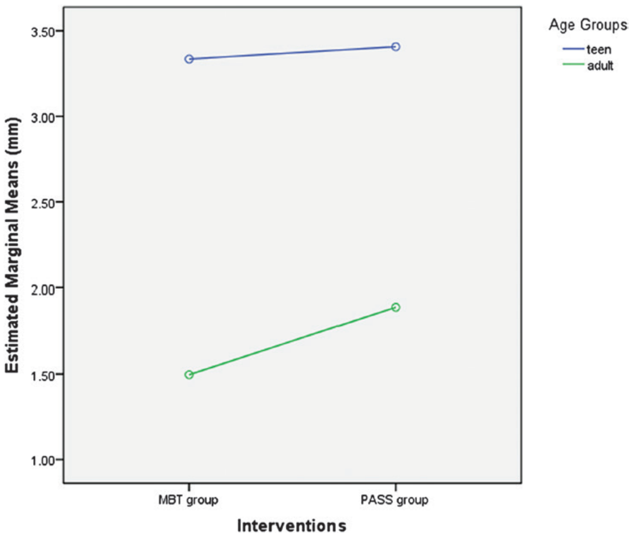

Figure 4. Interaction effect between the interventions and age groups.

were significantly different. The anterior teeth were retracted more in the MBT group than in the PASS group. The difference might be because that the prescription of torque in the anterior teeth was larger in the PASS appliance (Supplementary Tables S2 and S3). The 0.020-inch slot size of the brackets had less clearance and, furthermore, the curve of spee was maintained in each upper archwire during treatment.

Effect of growth and dentoalveolar compensation on anchorage control

Natural growth and development are helpful for malocclusion improvement under a certain condition. Growth and dentoalveolar compensation can be double-edged swords. Harris *et al.* (27) found that Class II malocclusion could be corrected by tooth movement plus the mandibular response in treatment for adolescents, whereas in adult treatment Class II malocclusion could be accomplished only by tooth movement. In the other way, Björk and Skieller (28) found that the upper molars moved forward to compensate for mandibular growth upon the superimposition of metallic implants. A unique longitudinal study by Zhang *et al.* (29) based on oblique radiographs and implants showed that the average cumulative

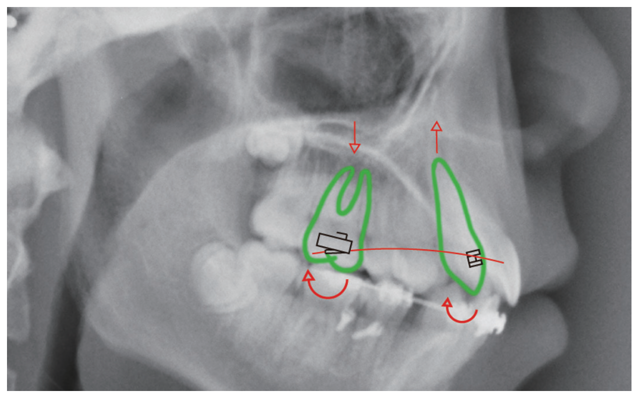

Figure 5. When the NiTi wire is inserted into the −25 degree auxiliary tube, the upper first molar attained a downward, backward moment whereas the canine attained an upward, backward moment.

eruption of the upper first molar was 12.1 ± 2.1-mm downward and 3.8 ± 1.7-mm forward from 8.5 years to 16 years of age. The upper canines showed uprighting during eruption and then tipped forward when the occlusion was established. Apparently, the growth pattern affected the extent of tooth movement. The different extent of tooth movement reminded orthodontists of a phenomenon that might be overlooked: in addition to mechanical anchorage loss, craniofacial growth could lead to physiologic anchorage loss. Ganzer *et al.* (30) found that the mesial displacement of the upper first molar still occurred in the alignment stage before TADs had been loaded. Therefore, the mesial tipping or displacement of the upper molars due to growth and dentoalveolar compensation in the first stage of orthodontic treatment might be an important part in anchorage loss.

Feldmann and Bondemark (31) performed a review of studies on anchorage control and showed that non-appraisal of the influence of growth on young patients made it difficult to draw conclusions about the most efficacious ways to protect anchorage. From this perspective, PASS tries to improve anchorage control with regard to physiologic factors. The present study found no interaction between the interventions and age groups. The concept of protecting the physiologic anchorage in PASS gained the alike anchorage control in juveniles compared with conventional methods.

Limitations

The study was a single-centre study focussed on Class I/II malocclusion with the requirement of tooth extraction. In the present study, minimized randomization was performed to balance the multiple factors between the two groups. However, the complete elimination of confounding factors is difficult. Also, different alternatives of the anchorage devices in MBT groups might generate potential bias on outcomes. The loss of participants also introduced a moderate risk of attrition bias. The dropouts of this study influenced the power of the test and the generalizability of the results. A future study with a larger sample size and intermediate assessments should be performed.

Conclusions

The study elicited that, compared with the MBT method, PASS without an additional anchorage appliance could attain well control of molar anchorage in both juveniles and adults. PASS led to fewer incisor retractions, which might have resulted from its greater torque control in the anterior brackets. Physiologic anchorage loss is required extra attention in the orthodontic treatment.

Supplementary material

The supplementary material is available at *European Journal of Orthodontics* online.

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Conflicts of interest

T.X. is the inventor of PASS.

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