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Table 1 to 3 are available in the Supplementary Files section.

Direct versus Indirect Second Molar Engagement During Distal Jet Distalization in Adolescents with Erupted Maxillary Second Molars: A Retrospective Cephalometric Cohort Study

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Abstract

Background: When the maxillary second molars have erupted, the conventional Distal Jet loads only the first molars and moves the second molars indirectly. This study compared a Double Distal Jet (DDJ), which delivers a separate force to each molar, with the conventional Single Distal Jet (SDJ) during the distalization phase.

Methods: In this retrospective cohort, 34 of 116 screened adolescents with Class II division 1 malocclusion and erupted maxillary second molars (17 SDJ, 17 DDJ) were treated until a super Class I molar relationship was reached. Twenty-two cephalometric variables were measured before (T1) and after (T2) distalization. Class II severity, skeletal maturation and third-molar development were recorded. The primary outcome was second-molar distalization, analysed by ANCOVA adjusted for baseline value and age; generalized estimating equations (GEE) served as a sensitivity analysis. Secondary outcomes were corrected with the Benjamini–Hochberg procedure.

Results: Although the DDJ group included more full-cusp Class II cases and more advanced third molars, it reached the endpoint sooner (3.22 ± 0.86 vs 4.10 ± 1.16 months; adjusted difference -1.08 months, 95% CI -1.94 to -0.21 ; $p = 0.017$) and distalized the second molar twice as fast (1.73 vs 0.79 mm/month; $p = 0.002$). Second-molar distalization was greater with the DDJ (-5.35 ± 2.06 vs -3.01 ± 1.81 mm; adjusted difference -1.58 mm, 95% CI -2.84 to -0.32 ; $p = 0.016$); the GEE estimate was similar but less precise (-1.53 mm, $p = 0.091$). First-molar distalization and molar tipping did not differ. Overbite decreased more with the DDJ (adjusted difference -2.37 mm; $q = 0.026$), reaching an approximately edge-to-edge relationship. No other secondary difference survived correction.

Conclusions: Within the distalization phase, loading the second molar directly shortened the time to a super Class I endpoint by about one month, independent of Class II severity and

maturation, and doubled the rate of second-molar movement without additional tipping. The main cost was greater bite opening.

Keywords: Class II malocclusion; Molar distalization; Distal Jet; Second molar; Anchorage; Cephalometry

Introduction

Class II malocclusion is one of the most common reasons for orthodontic treatment. When it is predominantly dentoalveolar and maxillary, distalization of the maxillary molars is a common non-extraction option, and it is also used in mild skeletal discrepancies (1,2). It is generally recommended for patients with normal or reduced vertical dimensions because of its extrusive side effects (3). Intraoral non-compliance appliances such as the Distal Jet were developed to overcome the dependence of headgear on patient cooperation(4,5) .

Many adolescents and most adults present for distalization after the maxillary second molars have erupted. Whether an erupted second molar slows or limits first-molar distalization has been debated for years (6–8) . Some studies found no effect on the amount or duration of distalization (9–11) , whereas others reported a measurable effect (6,7,12). Much less is known about how to deal with the second molar when it is present.

The Distal Jet consists of a Nance button and bilateral open-coil springs that act near the centre of resistance of the first molar, a design intended to limit tipping and rotation (5,13,14) . In its conventional form (Single Distal Jet, SDJ) only the first molar is banded, so the second molar can only be pushed indirectly by the first. Sequential-distalization concepts suggest that the terminal tooth, which has unobstructed bone distal to it, should be moved first (15–17) . A Double Distal Jet (DDJ) that places a separate spring on each molar allows both molars to be loaded simultaneously while letting the second molar lead.

It can be expected that a tooth receiving a direct force moves more than one receiving an indirect force. What clinicians cannot predict from the design alone is (i) how much time is saved to reach the same occlusal endpoint, (ii) whether the order of molar movement changes, (iii) where the space for Class II correction comes from, i.e., molar movement or anchorage loss, and (iv) the vertical cost of adding a second loaded tooth. These trade-offs determine whether the modification is worth using. The aim of this study was therefore to compare the

DDJ with the SDJ during the distalization phase in adolescents with erupted second molars, focusing on the efficiency, the pattern of molar movement, the anchorage and the vertical side effects. The null hypothesis was that the two appliances do not differ in second-molar distalization, time to the endpoint or associated dentofacial changes.

Methods

Study design and participants

This retrospective cohort study was approved by the Ethics Committee of Uşak University (No. 546-546-08) and conducted in accordance with the Declaration of Helsinki. It is reported according to the STROBE statement (18) . At the start of treatment, all patients and their parents or legal guardians gave written informed consent for treatment and for the use of their records (radiographs, photographs and dental casts) for scientific purposes.

The records of patients treated with maxillary molar distalization in the Department of Orthodontics and Dentofacial Orthopedics, Faculty of Dentistry, Uşak University, between January 2022 and April 2025 were screened consecutively. Inclusion criteria were bilateral dental Class II division 1 malocclusion of maxillary dentoalveolar origin, fully erupted maxillary second molars, permanent dentition, age 12–19 years at the start of treatment, no previous orthodontic treatment and good general health. Exclusion criteria were craniofacial anomalies, systemic disease, missing or inadequate cephalograms, distalization with other methods, and additional mechanics during distalization. The appliance was selected by the treating clinician based on clinical judgement; allocation was not randomized.

Of the 116 patients screened, 82 were excluded: missing radiographs (n = 17); inadequate radiograph quality, defined as a missing or damaged cephalostat, blurring of the anterior region, or double contours in the molar region that prevented reliable identification of the first and second molars (n = 12); treatment with other distalization methods such as clear aligners

(n = 26); additional mechanics such as miniscrews (n = 19); and age outside the inclusion range (n = 8). The remaining 34 patients were included (SDJ, n = 17; DDJ, n = 17) (Figure 1).

For each patient, the following baseline characteristics were recorded: Class II molar severity from pretreatment dental casts (half cusp, approximately 2 mm, or full cusp, approximately 4 mm), skeletal maturation on the T1 cephalogram using the cervical vertebral maturation (CVM) method (19) , and the developmental stage of the maxillary third molars on the panoramic radiograph (germ, crown formation or root formation).

The sample size was calculated a priori (G*Power 3.1.9.7) for the primary outcome, second-molar distalization. A between-group difference of 1.57 mm (effect size $d = 1.31$) reported by Campos et al. (20), $\alpha = 0.05$ and power = 0.95 gave a minimum of 14 patients per group. Seventeen patients per group were included.

Appliances and treatment protocol

For the DDJ, bands were fitted to both the first and second molars. Occlusal rests of 0.7 mm stainless steel wire (Leone C0450-07, Florence, Italy) were bent on the first premolars. On each side, metal tubes (Dentaurum 80-015-00, Ispringen, Germany) reaching the midline of the second premolar were positioned horizontally for each molar. Arms of 0.9 mm stainless steel wire (Leone C0450-09) carried nickel–titanium open-coil springs (Rocky Mountain Orthodontics OCNT 10045, Denver, CO, USA). An acrylic Nance button embedded the tubes and was relieved from the palatal surfaces of the anterior teeth (Figure 2). The SDJ was identical except that only the first molars were banded and activated (Figure 3).

Each spring was activated to deliver 200 g. The DDJ therefore applied 200 g to each molar (400 g per side in total), whereas in the SDJ a single 200 g force acted on the first molar and was transmitted to the second molar through the contact point. Patients were reviewed every 3–4 weeks and the springs were reactivated to 200 g. The appliance was removed when a

super Class I first-molar relationship was reached on both sides, and the T2 cephalogram was taken at the same appointment.

Cephalometric analysis

Lateral cephalograms were taken at T1 and T2 with the same device, in natural head position and centric occlusion, and were traced in Dolphin Imaging 11.95 (Dolphin Imaging & Management Solutions, Chatsworth, CA, USA). Twenty-two variables describing the posterior teeth, anchorage unit, incisors, skeletal pattern and soft tissue were measured (Figure 4). Sagittal tooth positions were measured to the Sella vertical, a line perpendicular to the S–N plane through the anterior wall of the sella turcica at its intersection with the anterior clinoid process, a point that remains stable during growth (21) . Negative changes therefore indicate distal movement. For UL–E and LL–E, negative values indicate a position behind the E-line. The treatment rate was calculated for each patient as the distal displacement of the first and second molars divided by the distalization period (mm/month; 1 month = 30.44 days). The relative movement of the two molars was expressed as $\Delta S\perp U7 - \Delta S\perp U6$; a negative value means that the second molar moved further distally than the first. The space gained mesial to the first molar was calculated as $\Delta S\perp U4 - \Delta S\perp U6$.

To assess the method error, the T1 cephalograms of 14 randomly selected patients (7 per group) were retraced by the same examiner after 14 days. Agreement was quantified with the intraclass correlation coefficient, ICC (2,1) (22), and the Dahlberg formula ($\sqrt{\Sigma d^2/2n}$). Because the appliance design is visible on the radiographs, the examiner could not be blinded to group allocation.

Statistical analysis

Within-group changes ($T2 - T1$) were tested with paired t-tests and reported with 95% confidence intervals (CIs). Baseline characteristics were compared with Welch's t-test, and categorical characteristics with Fisher's exact (Fisher–Freeman–Halton) test.

Because the design included two time points, complete data and continuous outcomes, the primary between-group analysis was an analysis of covariance (ANCOVA) of each change score. Appliance group was the factor, and the baseline ($T1$) value and age were covariates (23). This approach accounts for baseline imbalance and regression to the mean. Age was included because it differed between the groups. The adjusted mean difference ($DDJ - SDJ$) is reported with its 95% CI and partial η^2 .

The distalization period and molar rates were analysed with linear models adjusted for age, Class II severity (full vs half cusp), skeletal maturation (postpubertal, CS4–CS6, vs not) and third-molar development (crown or root formation vs germ). The distalization period was not used as a covariate in the main models because it is a consequence of the appliance rather than a pretreatment confounder.

Multiplicity was handled hierarchically. The single primary outcome ($\Delta S \perp U7$) was tested at $\alpha = 0.05$. The three efficiency outcomes formed one secondary family, and the remaining 21 cephalometric variables formed a second, exploratory family. Within each family, p-values were adjusted with the Benjamini–Hochberg false-discovery-rate procedure (24), and $q < 0.05$ was considered significant.

The sensitivity analyses were as follows: (i) the ANCOVA additionally adjusted for Class II severity, skeletal maturation and third-molar development, separately and together, and for the distalization period; (ii) generalized estimating equations (GEE; Gaussian family, identity link, exchangeable working correlation, robust sandwich variance) with group, time, group $\times$ time, age and age $\times$ time; and (iii) the Mann–Whitney U test on change scores. Residual

normality was checked with the Shapiro–Wilk test. Analyses were performed with IBM SPSS Statistics 29.0 (IBM Corp., Armonk, NY, USA).

Results

Participants and method error

Sex distribution was similar in the two groups (SDJ 9 female/8 male, DDJ 10/7; $p > 0.999$). The DDJ patients were older (15.71 ± 1.43 vs 13.95 ± 1.28 years; $p < 0.001$) and had more advanced third-molar development: crown or root formation in 15 of 17 DDJ patients vs 7 of 17 SDJ patients ($p = 0.016$) (Table 1). Skeletal maturation was more advanced in the DDJ group (postpubertal: 10 vs 6 patients; prepubertal: 2 vs 8), but the difference was not significant ($p = 0.096$). Full-cusp Class II was twice as common in the DDJ group (6 vs 3 patients; $p = 0.438$).

Of the 22 baseline cephalometric variables, only overbite differed (SDJ 3.39 ± 1.02 mm, DDJ 2.18 ± 1.25 mm; $p = 0.004$) (Additional file 1: Table S2). Intra-examiner agreement was excellent (ICC 0.90–1.00; Dahlberg error 0.10–0.63 mm) (Additional file 1: Table S1).

Efficiency and pattern of molar movement

The super Class I endpoint was reached sooner with the DDJ (3.22 ± 0.86 vs 4.10 ± 1.16 months; $p = 0.018$). The difference persisted after adjustment for age, Class II severity, skeletal maturation and third-molar development (-1.08 months, 95% CI -1.94 to -0.21 ; $p = 0.017$; $q = 0.025$) (Table 1). Full-cusp cases required about 0.9 months longer than half-cusp cases in both groups. The second molar moved about twice as fast with the DDJ (1.73 ± 0.70 vs 0.79 ± 0.50 mm/month; adjusted difference 0.98 mm/month, 95% CI 0.41 to 1.55; $q = 0.005$). First-molar rate was also higher (1.38 ± 0.61 vs 0.88 ± 0.54 mm/month), but not significantly after adjustment ($q = 0.055$).

Both appliances distalized both molars significantly (Table 2). For the primary outcome, the second molar moved -5.35 ± 2.06 mm with the DDJ and -3.01 ± 1.81 mm with the SDJ (unadjusted difference -2.34 mm, $d = -1.21$; ANCOVA-adjusted difference -1.58 mm, 95% CI -2.84 to -0.32 ; $p = 0.016$; partial $\eta^2 = 0.18$) (Table 3). First-molar distalization did not differ after adjustment (-4.24 ± 1.74 vs -3.33 ± 1.89 mm; adjusted difference -0.45 mm, 95% CI -1.72 to 0.83 ; $p = 0.479$).

The sequence of molar movement differed between the appliances (Figure 5). With the DDJ, the second molar moved 1.11 mm (95% CI 0.76 – 1.45) further distally than the first molar; with the SDJ it moved 0.32 mm (95% CI -0.02 to 0.67) less than the first molar (between-group difference -1.43 mm, 95% CI -1.89 to -0.96 ; $p < 0.001$; age-adjusted $p < 0.001$). Molar tipping did not differ between the groups (U6–PP, adjusted $p = 0.413$; U7–PP, adjusted $p = 0.284$), although the second molar tipped distally within both groups (SDJ -4.80° , DDJ -3.50°).

Anchorage

The space gained mesial to the first molar was similar in the two groups (SDJ 4.48 ± 2.78 mm, DDJ 4.03 ± 1.81 mm; adjusted $p = 0.352$), but its source differed. With the SDJ, the first premolar moved mesially by 1.15 ± 2.27 mm ($p = 0.053$). With the DDJ, it did not move mesially (-0.21 ± 1.51 mm; $p = 0.569$). The adjusted between-group difference was -1.39 mm (95% CI -3.01 to 0.23 ; $p = 0.090$; GEE $p = 0.026$). Incisor proclination was observed in both groups: U1–SN increased by 1.78° with the SDJ ($p = 0.008$) and by 1.93° with the DDJ ($p = 0.096$), and U1–NA increased by 1.21° with the SDJ ($p = 0.122$) and by 2.39° with the DDJ ($p = 0.041$). Overjet increased only with the DDJ ($+1.01$ mm; $p = 0.020$). None of the incisor differences between the groups was significant after adjustment (all $q \geq 0.29$).

Vertical, skeletal and soft-tissue changes

Overbite decreased in both groups, but more with the DDJ (-3.09 ± 2.04 vs -1.56 ± 1.51 mm; adjusted difference -2.37 mm, 95% CI -3.73 to -1.01 ; $p = 0.001$; $q = 0.026$; GEE $p = 0.027$). The difference remained after adjustment for the lower baseline overbite of the DDJ group (Additional file 1: Table S3). At T2, cephalometric overbite was below 0 mm in 14 of 17 DDJ patients and 1 of 17 SDJ patients; clinically, these patients presented an approximately edge-to-edge incisor relationship. Within the DDJ group, SN–GoGn ($+2.41^\circ$; $p = 0.008$) and the vertical position of the first molar (U6–PP $+1.00$ mm; $p = 0.020$) and second molar (U7–PP $+1.21$ mm; $p = 0.041$) increased. The between-group differences for SN–GoGn ($p = 0.047$) and U7–PP ($p = 0.038$) were nominally significant but did not survive correction ($q = 0.25$). The first premolar extruded in both groups.

No sagittal skeletal variable (SNA, SNB, ANB) changed within or between the groups. The lower lip moved back relative to the E-line only with the DDJ (-1.05 mm; $p = 0.019$). The between-group difference ($p = 0.021$) did not survive correction ($q = 0.22$).

Sensitivity analyses

The primary result was robust to additional adjustment for Class II severity ($p = 0.013$), skeletal maturation ($p = 0.019$), third-molar development ($p = 0.023$), all three together ($p = 0.027$) and the distalization period ($p = 0.038$), and to the Mann–Whitney U test ($p = 0.001$) (Additional file 1: Table S3).

In the GEE model adjusted for age (age and age $\times$ time), the estimated second-molar difference was similar (-1.53 mm), but the confidence interval was wider (95% CI -3.30 to 0.24 ; $p = 0.091$). This model analyses the raw change and does not use the strong association between the baseline position and the amount of second-molar movement ($r = -0.56$). The overbite difference was significant in every model.

Discussion

Because the DDJ applies a force directly to the second molar, greater second-molar distalization was expected, and we do not present that finding as the main contribution. The contribution of this study is to quantify what the modification changes in practice when the treatment target is held constant. First, it shortened the time to a super Class I relationship by about one month, and this remained after accounting for Class II severity, skeletal maturation and third-molar development. Second, it doubled the rate of second-molar movement and reversed the order of molar movement, so that the second molar led instead of lagging behind. Third, the space for correction came from molar movement rather than premolar mesialization. Fourth, it caused substantially more bite opening. These magnitudes cannot be derived from the appliance design and are what a clinician needs when choosing between the two designs.

Treatment continued in both groups until the same occlusal endpoint. This is why first-molar displacement was similar, and it should not be read as evidence that the appliances are equally effective at the first molar. With a fixed endpoint, the informative outcomes are those not dictated by the treatment goal: the time and rate needed to reach the endpoint, the behaviour of the second molar, and the unwanted movements of the anchorage unit and the vertical dimension. The DDJ group started with more full-cusp cases and more advanced third molars, both of which would be expected to lengthen distalization (6,7). It nevertheless finished sooner, which argues against the efficiency gain being an artefact of case selection.

Efficiency and sequence of molar movement

The DDJ reached the endpoint about one month sooner and moved the second molar about twice as fast. The key biomechanical difference is how the force is distributed. Each spring delivered 200 g, so with the DDJ each molar received its own 200 g, whereas with the SDJ a single 200 g force had to move two molars, roughly 100 g per tooth. About 70–120 g is

considered adequate for bodily movement of a molar (25). The DDJ therefore brings each molar into this range, whereas the SDJ leaves both molars at the lower limit.

With the SDJ, the second molar trailed the first, consistent with being pushed through the contact point. With the DDJ, it moved 1.1 mm ahead of the first. Sequential-distalization concepts hold that the terminal molar, which has no distal neighbour and is surrounded by relatively cancellous bone, should be moved first so that the first molar can follow with less resistance (15–17). Conventional sequential protocols achieve this in separate stages, which lengthens treatment (8). The DDJ loads both molars simultaneously, and the second molar still leads. This suggests that simultaneous loading achieves the intended sequence without a staged protocol, which may explain the shorter distalization period. As the study is retrospective, this remains a biomechanically plausible interpretation rather than proven causation.

The amount of second-molar distalization should be interpreted with more caution than the efficiency outcomes. The DDJ patients were older, and the difference was smaller after age adjustment (−1.58 instead of −2.34 mm). It remained significant in the ANCOVA and all its sensitivity models. In the GEE model, which does not adjust for baseline position, it was borderline. The rate of movement and the time to the endpoint were more robust than the amount of movement. This is expected, because the fixed endpoint limits how far the teeth are moved but not how quickly.

A saving of one month in the distalization phase is modest and should be put in context. It is only clinically meaningful if the shorter phase is not offset later by longer anchorage recovery or bite correction. Because not all patients had completed comprehensive treatment, total treatment time could not be evaluated, and we deliberately limited the conclusions to the distalization phase.

Anchorage

Anchorage loss is the main drawback of tooth-borne distalizers and usually appears as mesial movement of the premolars and proclination of the incisors (5,26–28) . The DDJ doubles the reactive load on the Nance button (400 g vs 200 g per side), so greater anchorage loss might be expected. This was not observed. The space gained mesial to the first molar was similar with the two appliances, but with the SDJ about a quarter of it came from premolar mesialization, within the range reported for the conventional Distal Jet (5,27,29) . With the DDJ, the premolars stayed in place. Incisor proclination occurred in both groups, and no incisor difference between the groups survived correction. The data therefore do not show that the DDJ increases anchorage loss despite its larger reactive load. Whether it reduces anchorage loss needs a larger sample; the premolar difference was significant in the GEE analysis but not in the ANCOVA.

Vertical effects

The main cost of the DDJ was vertical. Overbite decreased by about 2.4 mm more than with the SDJ after adjustment, and most DDJ patients finished distalization with an approximately edge-to-edge incisor relationship. This was the only secondary outcome to survive false-discovery-rate correction, and it was robust in every sensitivity analysis. It is consistent with the molar extrusion and increase in SN–GoGn seen within the DDJ group. Molar extrusion and clockwise mandibular rotation are known side effects of distalization (5,26) . A similar increase in molar extrusion was reported when the second molars were included in a Quad Pendulum appliance (8). Engaging a second tooth distal to the centre of resistance of the dentition, with twice the total force, probably increases the extrusive moment on the posterior segment. The DDJ group also started with a smaller overbite, but the between-group difference remained after adjustment for baseline overbite. Clinically, this finding argues

against the DDJ in patients with reduced overbite or a hyperdivergent pattern. Whether the bite closes again during the subsequent fixed-appliance phase could not be evaluated.

Growth, skeletal and soft-tissue effects

Neither appliance produced sagittal skeletal change, in agreement with the view that intraoral distalizers act at the dentoalveolar level (5,30). The two groups differed in skeletal maturation. Most SDJ patients were prepubertal or pubertal, whereas most DDJ patients were postpubertal. Over the short distalization period (3–4 months), growth-related changes are expected to be small. Adjusting for maturation did not change any of the main findings. However, some growth contribution to the vertical measurements in the younger SDJ group cannot be excluded. The soft-tissue changes were small, and none survived correction, consistent with studies reporting minimal profile change during the distalization phase (5,30,31).

Clinical implications

In adolescents with erupted second molars, both appliances achieved a super Class I relationship through dentoalveolar movement. The DDJ reached it about one month sooner, independent of Class II severity. It moved the second molar ahead of the first without extra tipping and did not increase premolar mesialization. Its main drawback is bite opening. Appliance selection should therefore depend mainly on the vertical pattern and the initial overbite. The DDJ is a reasonable choice in normodivergent or hypodivergent patients with normal or deep overbite, whereas the SDJ is the more conservative choice when overbite is reduced.

Limitations

This study has several limitations. First, it was retrospective and non-randomized, and the treating clinician chose the appliance. The groups differed in age, third-molar development

and, non-significantly, in skeletal maturation and Class II severity. These factors were addressed by adjustment and sensitivity analyses, but residual confounding cannot be excluded. Second, the DDJ differs from the SDJ in both how force is distributed and how much total force is applied (400 vs 200 g per side), and the two effects cannot be separated. Excluding radiographs with double contours in the molar region may have removed patients with asymmetric molar movement. And the outcomes were limited to the distalization phase. Because not all patients had completed comprehensive treatment, total treatment duration, anchorage recovery, bite closure and long-term stability could not be assessed. Two-dimensional cephalometry superimposes the left and right molars and cannot measure rotations. Cone-beam computed tomography is not justified for routine distalization under the ALARA principle. Analysis of dental casts would be a useful addition in future studies.

Conclusions

Within the distalization phase in adolescents with erupted maxillary second molars, the Double Distal Jet reached a super Class I molar relationship about one month sooner than the conventional Single Distal Jet. This held after adjustment for age, Class II severity, skeletal maturation and third-molar development. It was also associated with twice the rate of second-molar distalization, with the second molar moving ahead of the first and no additional molar tipping or premolar mesialization. The main drawback was greater bite opening, which reached an approximately edge-to-edge incisor relationship in most patients. The Double Distal Jet may therefore be preferable when faster distalization is desired in patients with normal or deep overbite, whereas the Single Distal Jet is the more conservative option when overbite is reduced. Whether the shorter distalization phase shortens total treatment time remains to be determined.

Abbreviations

ANCOVA: Analysis of covariance

CI: Confidence interval

CVM: Cervical vertebral maturation

DDJ: Double Distal Jet

FDR: False discovery rate

GEE: Generalized estimating equations

ICC: Intraclass correlation coefficient

OP: Occlusal plane

PP: Palatal plane

SDJ: Single Distal Jet

STROBE: Strengthening the Reporting of Observational Studies in Epidemiology

T1/T2: Before/after distalization

Declarations

Ethics approval and consent to participate

The study was approved by the Ethics Committee of Uşak University (No. 546-546-08) and conducted in accordance with the Declaration of Helsinki. All patients and their parents or legal guardians gave written informed consent at the start of treatment for the use of their records for scientific purposes.

Consent for publication

Not applicable.

Availability of data and materials

The datasets used and analysed during the current study are available from the corresponding author on reasonable request.

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions

IAD: study design, data collection, cephalometric analysis and writing of the manuscript.

IEG: conceptualization, statistical analysis and critical review of the manuscript. All authors read and approved the final manuscript.

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Not applicable.

Additional file 1 (.xlsx). Table S1: intra-examiner reliability; Table S2: baseline comparison; Table S3: sensitivity analyses (ANCOVA with additional covariates, GEE, Mann–Whitney U test); Table S4: individual-level data.

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Figure 1

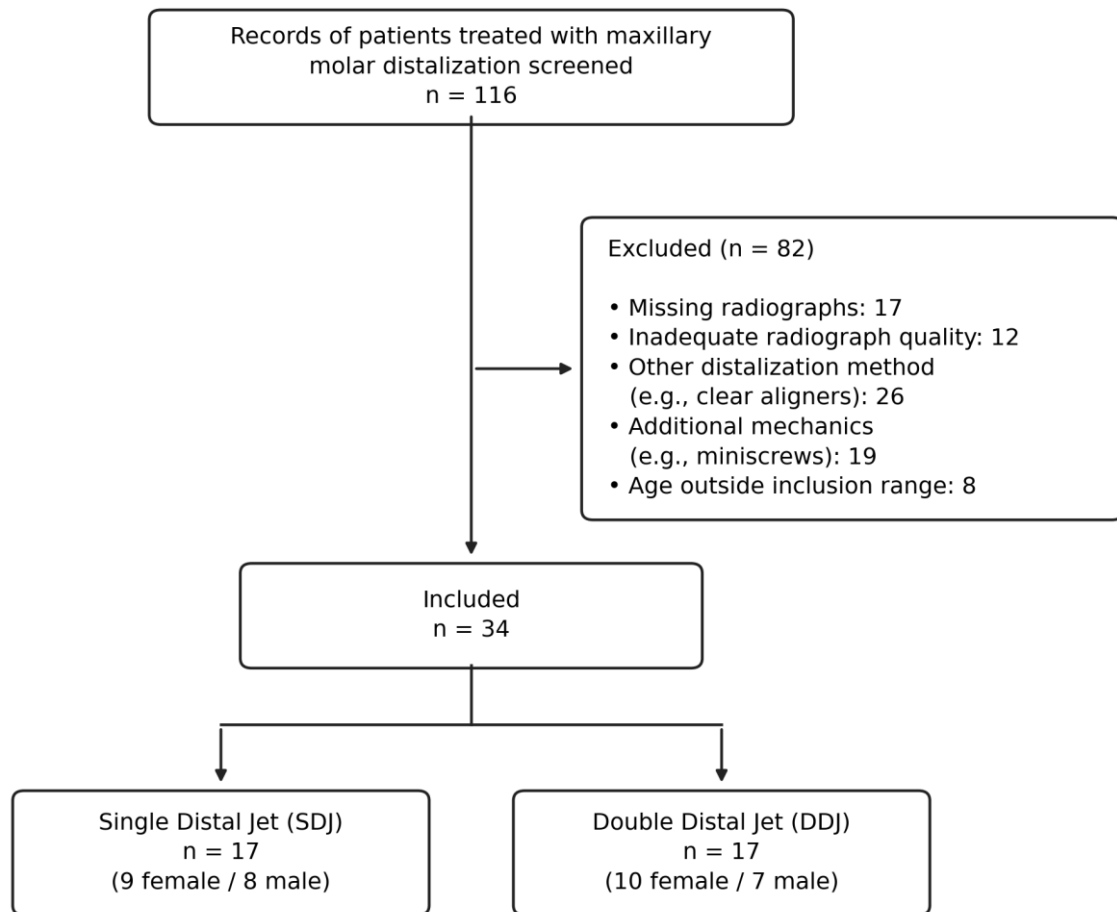


Figure 1. Flow diagram of patient selection.

Figure 2



Figure 2. Double Distal Jet (DDJ): bands on the first and second molars, with a separate tube, arm and open-coil spring (200 g) for each molar, anchored to a Nance button and occlusal rests on the first premolars.

Figure 3

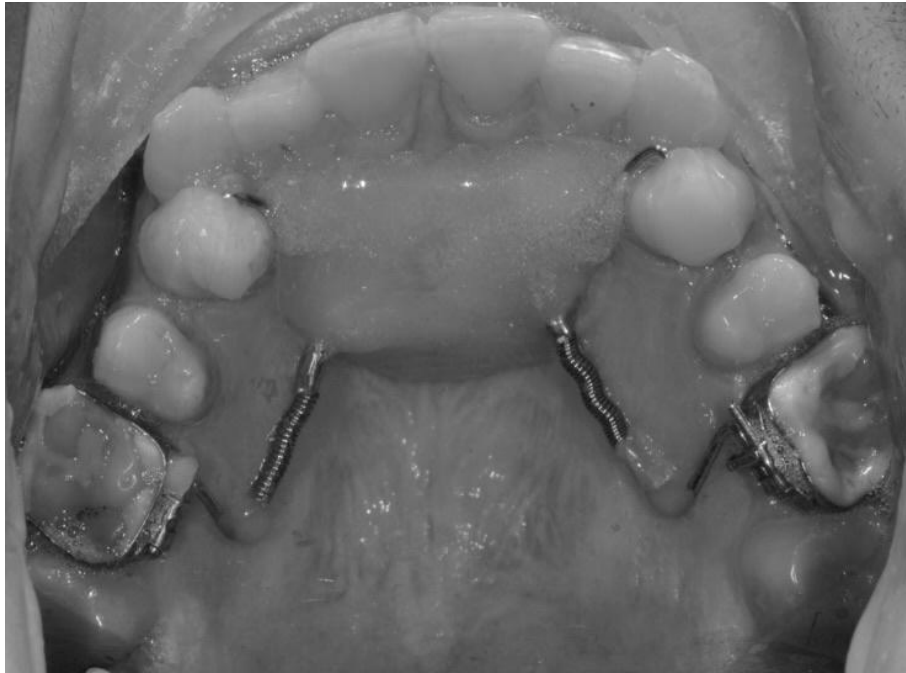


Figure 3. Single Distal Jet (SDJ): the conventional design, in which only the first molars are banded and activated (200 g per side).

Figure 4

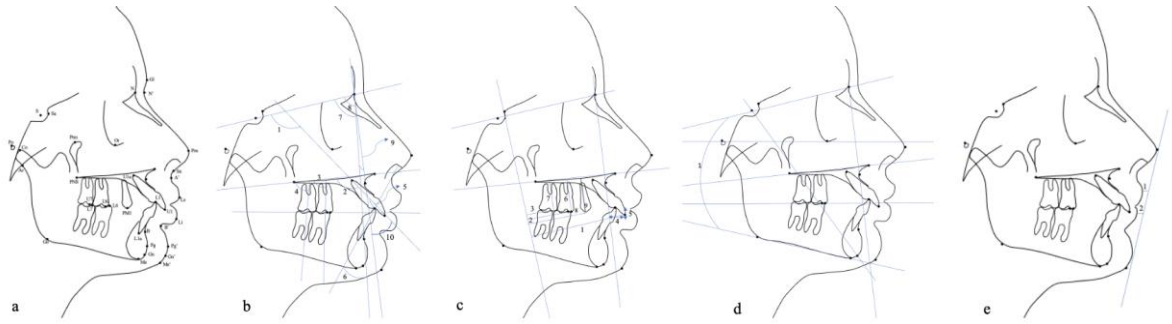


Figure 4. Cephalometric landmarks and measurements used in the study. (a) Cephalometric landmarks. (b) Angular measurements: 1, U1–SN; 2, U1–PP; 3, U6–PP; 4, U7–PP; 5, interincisal angle; 6, L1–NB; 7, SNB; 8, SNA; 9, ANB; 10, U1–NA. (c) Linear dental measurements: 1, S⊥U1; 2, S⊥U6; 3, S⊥U7; 4, overjet; 5, overbite; 6, U6–PP; 7, U7–PP; 8, S⊥U4; 9, U4–PP. (d) Vertical skeletal measurement: 1, SN–GoGn. (e) Soft-tissue measurements: 1, UL–E; 2, LL–E. Sagittal positions (S⊥) were measured to the Sella vertical, a line perpendicular to S–N through the anterior wall of the sella turcica. U1, maxillary central incisor; U4, maxillary first premolar; U6, maxillary first molar; U7, maxillary second molar; L1, mandibular central incisor; PP, palatal plane; UL/LL–E, upper/lower lip to E-line.

Figure 5

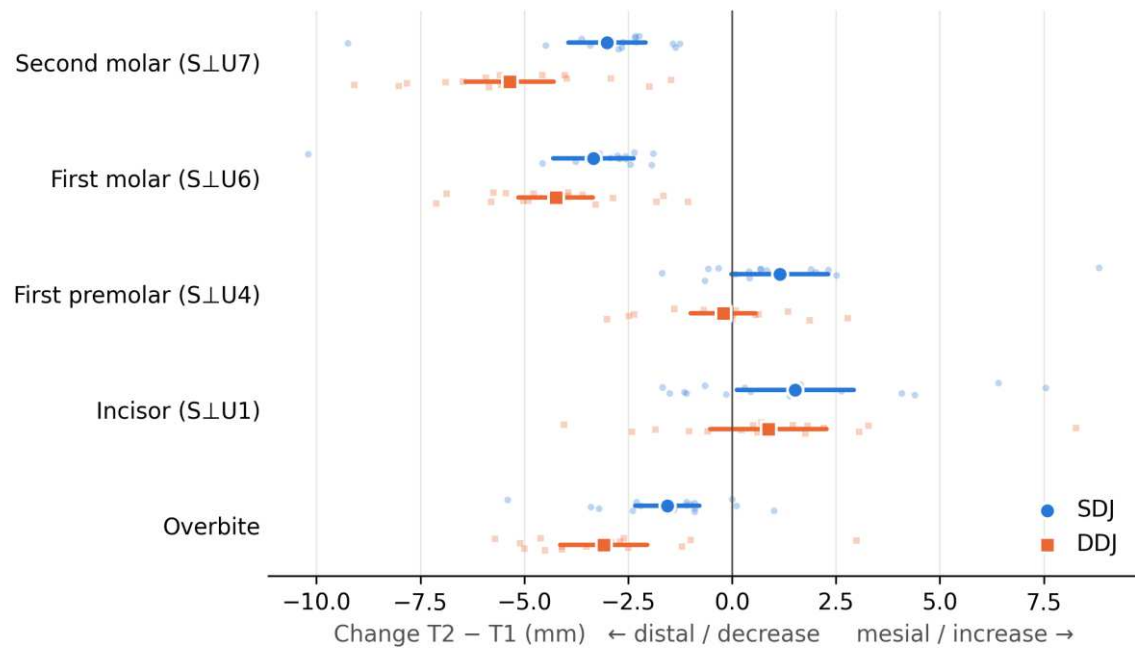


Figure 5. Sagittal changes (T2 – T1) of the second molar, first molar, first premolar and incisor, and change in overbite, by appliance. Large markers show group means with 95% confidence intervals; small markers show individual patients. Negative values indicate distal movement or a decrease.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- [TablesDDJvsSDJ.docx](#)