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Systematic Review
Orthognathic Surgery

Mandibular distraction osteogenesis: a systematic review of stability and the effects on hard and soft tissues

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Abstract. Mandibular distraction osteogenesis (MDO) has been widely adopted in modern maxillofacial surgery due to its less invasive approach and the consistent aesthetic and functional improvements obtained. The aim of the present systematic review was to analyze the available evidence on the skeletal and soft tissue effects of MDO. The medical literature was searched to identify all peer-reviewed papers meeting the selection criteria for the final review process. A three-point grading system was used to rate the methodological quality of the selected papers. The PICO approach was used to extract data from the selected papers. The search strategy yielded eight relevant publications. The quality of the collected evidence was low to moderate. Vertical and sagittal skeletal dimensions increased significantly, by a mean of 5–10 mm ($P < 0.05$). Regarding the sagittal positioning of the lips and surrounding structures, a 90% correspondence between skeletal and soft tissue cephalometric points was observed. Significant skeletal relapse was reported, however it did not worsen the results of treatment significantly.

Key words: mandibular distraction osteogenesis; orthognathic surgery; mandibular advancement; orthodontic class II.

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In recent years, new techniques have been adopted for the surgical treatment of class II patients. One such technique is mandibular distraction osteogenesis (MDO), which is a less invasive approach and is associated with consistent aesthetic and functional improvements.[1,2] MDO was first presented by Rosenthal in 1927, who performed the first mandibular distraction with a tooth-borne appliance that was gradually activated over a period of 1-month.[3] This technique was adopted due to the good results obtained in the treatment of syndromic patients with bone length discrepancies ranging from 15 to 50 mm. MDO was then also applied for the correction of significant orthognathic problems (e.g. skeletal class II discrepancies requiring less than 20 mm of mandibular advancement).[4]

According to modern orthodontic guidelines, the primary objective of orthognathic surgery has changed from the restoration of normal occlusion to the correction of frontal and profile aesthetics.[5,6] Thus, treatment planning starts from the newly defined endpoint of a patient's soft tissue profile, and the necessary dental and skeletal movements are derived from this. On the basis of the

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aesthetic paradigm, different segmental osteotomies are chosen by the surgeon to achieve the best aesthetic results.[5] An accurate prediction of the postoperative facial profile is also an essential step in the treatment planning process for combined surgical–orthodontic therapy.[5]

The aim of the present systematic review was to answer the following clinical research questions: (1) What are the skeletal effects of MDO, after surgery and after long-term follow-up? (2) What are the effects of MDO on the soft tissues, after surgery and after long-term follow-up? (3) To what degree do the skeletal and soft tissues relapse after MDO?

Materials and methods

The systematic review protocol was registered in PROSPERO (the International Prospective Register of Systematic Reviews, http://www.crd.york.ac.uk/PROSPERO/; CRD42015024635).

The available scientific literature was searched in May 2015 to identify all medical articles reporting the effects of MDO on the soft and hard tissues. The following search strategy was used and adapted to the principal medical databases (MEDLINE, Embase, Scopus, Cochrane Oral Health Group Trial Register and Cochrane Register of Controlled Trials, Web of Science, LILACs, SciELO, and Google Scholar): ((''MDO'' OR ''mandibular distraction osteogenesis'' OR ''orthognathic surgery'') AND ((skeletal OR hard tissue* OR soft tissue*) AND (profile OR relapse OR effect* OR stability))). A hand-search was performed in the authors' personal libraries and in the references of the studies included to identify additional papers.

The inclusion and exclusion criteria applied in this systematic review are reported in Table 1. Two of the authors (RR, BV) independently removed duplicate papers and selected the studies for final inclusion.

The data extraction was performed independently by two of the authors (GR, BV) using the PICO approach (Population, Intervention, Comparator, and Outcomes). For the purposes of this systematic review, the PICO format was modified adding the study design field (PICOS).[7] In the case of missing information on the characteristics of an included study, the authors of that study were contacted.

The primary outcome was the analysis of soft and hard tissue modifications occurring after MDO. The secondary outcomes were the stability of the treatment and other collateral factors (e.g., patient compliance, costs).

According to the CRD (Centre for Reviews and Dissemination, University of York, York, UK)[8] and PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses)[9] statements, the evaluation of methodological quality gives an indication of the strength of evidence and of the risk of bias present in the study. However, no single approach for assessing the risk of bias best fits all systematic reviews.[9] A three-point grading system, described by the Swedish Council on Technology Assessment in Health Care (SBU) and the CRD, was used to rate the methodological quality of the selected papers; this was done by two authors (RR, BV) (Tables 2 and 3).[8,10]

Results

The search strategy yielded eight relevant publications.[11–18] One study was prospective and non-randomized[11] and seven studies were retrospective and non-randomized[12–18] (Table 4). The article selection process is illustrated in the PRISMA flow diagram given in Fig. 1.

The sample size of the individual studies ranged from 10 to 40 subjects, with a total of 181 subjects. Mean age at the start of treatment in the evaluated samples ranged from 7.7 to 29.8 years.

From a methodological point of view, the selected papers used different procedures to detect treatment effects: six studies used measurements on cephalometric tracings,[11–14,17,18] one study adopted computed tomography (CT),[16] and one study used panoramic and lateral cephalometric radiographs.[15]

Soft tissues parameters were analyzed in three studies,[11,14,17] while all the other papers focused on hard tissues.[12,13,15,16,18]

Quality analysis

According to the SBU tool,[10] the quality of the collected evidence was moderate (grade B) in four studies,[11,16–18] and low (grade C) in the other four.[12–15] Thus, conclusions with a limited level of evidence could be drawn from the review process. The most important sources of bias were the absence of information on randomization procedures, the lack of adequate blinding procedures, and method error analysis in all of the studies graded C. The quality grading of the selected papers is shown in Table 4.

Skeletal vertical dimension

Using panoramic radiographs, Aizenbud et al. (2010) recorded a mandibular modification of 12.03 mm for the right side and 10.87 mm for the left side ($P < 0.0001$).[15] At follow-up, a relapse of 2.04 mm on the mandibular right side was seen on panoramic radiographs ($P = 0.018$). On analysis of lateral X-rays, the right mandibular side height increased 10.43 mm and the left side increased 10.45 mm after treatment ($P < 0.0001$). A relapse of 1.22 mm was registered for the mandibular left side on cephalometric analysis ($P = 0.039$).

Breuning et al. reported the results of two studies in 2004; they observed significant changes in the palatal plane–mandibular plane angle (SpP/MP) after MDO (3.9°, $P < 0.001$).[12,13]

In 2012, Metzler et al. demonstrated an occlusal plane inclination of 1.9° ($P < 0.01$) together with a vertical bone loss of 3.5 mm ($P < 0.01$) after surgery.[16]

El-Bialy et al. (2013) reported a significant increase in mandibular plane angle immediately after MDO and at follow-up (T1–T2 5.3°, T1–T4 4.3°) ($P < 0.05$), while a relapse occurred after 8 years (T2–T4 −1.0°).[11] Furthermore, total anterior facial height (TAFH) and lower anterior facial height (LAFH) increased significantly after MDO and at follow-up (TAFH: T1–T2 5 mm, T1–T4 4.8 mm; LAFH (%): T1–T2 2.0, T1–T4 1.7; LAFH (ANS–Me) (mm): T1–T2 4.7, T1–T4 4.1).

Table 1. Selection criteria.

Inclusion criteria	Exclusion criteria
• Human clinical trials • Sample with at least 10 subjects • MDO with intra-oral distractors, and accepted genioplasty • Evaluation of immediate and/or long-term skeletal and/or soft tissue effects of MDO	• Syndromic or medically compromised patients • Case reports, case series of fewer than 10 patients, descriptive studies, review articles, opinion articles • Any surgical intervention other than MDO (i.e., Le Fort I, other types of mandibular surgery, etc.)

MDO, mandibular distraction osteogenesis.

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Table 2. SBU criteria for grading the studies assessed.

Grade A—High value of evidence
All criteria should be met:
- Randomized clinical study or a prospective study with a well-defined control group
- Defined diagnosis and endpoints
- Diagnostic reliability tests and reproducibility tests described
- Blinded outcome assessment

Grade B—Moderate value of evidence
All criteria should be met:
- Cohort study or retrospective case series with defined control or reference group
- Defined diagnosis and endpoints
- Diagnostic reliability tests and reproducibility tests described

Grade C—Low value of evidence
One or more of the conditions below:
- Large attrition
- Unclear diagnosis and endpoints
- Poorly defined patient material

SBU, Swedish Council on Technology Assessment in Health Care.

Table 3. Definitions of the level of evidence.

Level	Evidence	Definition
1	Strong	At least two studies assessed as level ‘A’
2	Moderate	One study at level ‘A’ and at least two studies at level ‘B’
3	Limited	At least two studies at level ‘B’
4	Inconclusive	Fewer than two studies at level ‘B’

Skeletal sagittal dimension

Aizenbud et al. reported a significant elongation in the horizontal dimension of both sides, as well as changes in the linear distance between gonion (Go) and menton (Me) ($P < 0.0001$).[15] Measurements on panoramic radiographs revealed an average increase after distraction of 8.51 mm for the right side (9.98%, $P < 0.0001$) and 8.13 mm for the left side (9.33%, $P < 0.0001$). On lateral cephalometric radiographs, the average measured differences after MDO were 6.80 mm for the right side (10.77%, $P < 0.0001$) and 7.61 mm for the left side (11.88%, $P < 0.0001$). At long-term follow-up, a relapse of 0.5–2.5 mm was recorded for both the panoramic and cephalometric measurements (right and left sides). This relapse effect was found to be statistically significant for the panoramic measurements ($P = 0.049$) and cephalometric measurements ($P = 0.006$) of the left side.

Breuning et al. observed an increase of 5.9° in the sella–nasion–B-point (SNB) angle, together with a decrease of 5.8 mm in the Wits index and of 3.7° for the A-point–nasion–B-point (ANB) angle ($P < 0.001$).[12] A significant mandibular advancement of 8.2 mm without tipping was obtained by Metzler et al. in their study from 2012 ($P < 0.01$).[16] The authors also reported an apical base enlargement of 4.0 mm ($P < 0.01$), as well as an alveolar process enlargement of 6.4 mm ($P < 0.01$). Joss et al. (2013) registered an advancement of 3.6 mm for point B, of 2.2 mm for the alveolar surgical anterior base point (ASAB), and of 6.2 mm for incisor inferior immediately after MDO ($P = 0.000$).[17]

According to Joss et al., a larger gonial angle before treatment (mean 125.9° ± 8.1°, range 115.6°–145.8°) was significantly correlated with a relapse at long-term follow-up in the horizontal position of pogonion (Pog) (mean 0.4 ± 1, range −1.7 to 1.8 mm) ($P = 0.024$, $R = 0.544$).[18] Larger values of nasal line–mandibular line angle (NL–ML) before treatment (mean 26.2° ± 6.4°, range 16.2°–44.8°) showed significant correlations with a smaller relapse at long-term follow-up in the horizontal values of point B (mean 0.1 ± 1.2, range 2.2–2.1) ($P = 0.006$, $R = 0.633$) and Pog (mean 0.4 ± 1.0, range 1.6–2.9) ($P = 0.000$, $R = 0.773$). Similar results were observed for larger nasion–sella line–mandibular line (NSL–ML) angle (T1) (mean 33.6° ± 7.9°, range 21.4°–53.7°) and a smaller relapse in the horizontal value of point B (mean 0.3 ± 1.3, range 2.7–3.3) ($P = 0.047$, $R = 0.487$) and Pog (mean 0.4 ± 1.0, range 1.6–2.9) ($P = 0.012$, $R = 0.596$).

The Jarabak ratio (sella–gonion/nasion–menton) before treatment (mean 64.5 ± 6.5, range 49.2–75.7) was significantly correlated with a larger relapse at follow-up at point B (mean −0.3 ± 1.3, range 2.7–3.3) ($P = 0.026$, $R = 0.538$) and Pog (mean 0.5 ± 0.1, range 0.8–2.4) ($P = 0.014$, $R = 0.586$).

El-Bialy et al. observed that after MDO and at long-term follow-up, a significant increase in SNB angle (T1–T2 1.9°, T1–T4 1.3°) ($P < 0.05$), gonion–gnathion (Go–Gn) (T1–T2 4.6 mm, T1–T4 4.5 mm), and condylion–gnathion (Cd–Gn) (T1–T2 5 mm, T1–T4 5.9 mm), together with a decrease in ANB angle (T1–T2 −1.9°, T1–T4 −2.4°) occurred.[11]

Soft tissue vertical dimension

Joss et al. reported a significant correlation between increasing patient age and a downward movement of Pog′ ($P = 0.014$, $R = 0.538$).[17] Furthermore, point B was significantly correlated with an upward movement of labrale inferior point ($P = 0.006$, $R = 0.637$) and stomion inferior point ($P = 0.019$, $R = 0.561$).

Soft tissue sagittal dimension

In 2006, Melugin et al. evaluated the effects of MDO on the hard to soft tissue movement ratio.[14] A mean advancement ratio of 1:0.9 for point B/Labiomental sulcus (LMS) and Pogonion/Soft tissue Pogonion (Pg/Pgs) was observed ($P < 0.0001$).

Joss et al. analyzed the soft tissue stability after MDO.[17] At long-term follow-up, the observed effect in labrale inferior was 24% of the advancement in incision inferior. Furthermore, the corresponding value for point B′ to point B was 88% and for labrale superior to incision inferior was 11%. The authors revealed a significant correlation between increasing patient age and a backward movement of the horizontal values of labrale inferior ($P = 0.045$, $R = 0.492$). Furthermore, a larger NL–ML′ angle preoperative was significantly correlated with a smaller horizontal change at labrale inferior ($P = 0.044$, $R = 0.494$). Significant correlations after MDO and at long-term follow-up in horizontal hard to soft tissue movements were registered for point B/B′ (T3–T1: $P = 0.003$, $R = 0.681$; T5–T3: $P = 0.017$, $R = 0.569$), incision inferior and labrale inferior (T3–T1: $P = 0.005$, $R = 0.649$; T5–T3: $P = 0.092$, $R = 0.422$), and incision inferior and labrale superior (T3–T1: $P = 0.067$, $R = 0.454$; T5–T3: $P = 0.012$, $R = 0.592$).

El-Bialy et al. showed significant variations in lower lip–aesthetic line distance (LL–E) after debonding and at follow-up (T2–T3 3.6 mm, T1–T4 3.1 mm, T2–T4 3.3 mm) ($P < 0.05$).[11] Thus, a significant correlation between LL–E line and L1/MPA was registered ($r = 0.64$, $P < 0.047$).

Table 4. PICOS criteria and SBU quality grading.

Author, year	Study design	Population Sex Age	Intervention	Comparison	Significant outcomes[a]	SBU grade
Breuning et al., 2004[12]	Retrospective study	26 patients 13 M, 13 F Mean age: 14.6 y (T0), 17.3 y (T1)	Headgear, fixed appliance, and DO	Fixed appliance and DO Before surgery	Duration of treatment**; SNB (°)**; ANB (°)**; Wits (°)**; SpP/MP (°)**; overbite**; overjet**	C
Breuning et al., 2004[13]	Retrospective study	26 patients 13 M, 13 F Mean age: 14.6 y (T0), 17.3 y (T1)	DO	Before surgery	Overbite**; SpP/MP (°)**	C
Melugin et al., 2006[14]	Retrospective study	27 patients 16 M, 11 F Mean age: 7 y 7 m	DO with internal device	Before surgery	B-point/LMS**; Pg/Pgs**	C
Aizenbud et al., 2010[15]	Retrospective cohort study	40 patients 20 F, 20 M Mean age: 15.45 ± 11.08 y, range: 5–55 y	DO	Before surgery	Mandibular vertical dimension (panoramic, cephalometric)** Vertical dimension relapse (panoramic right side, cephalometric left side)* Mandibular horizontal dimension (panoramic, cephalometric)** Horizontal dimension relapse (panoramic left side, cephalometric)*	C
Metzler et al., 2012[16]	Retrospective study	18 patients 7 M, 11 F Mean age: 25.05 y, range: 17–44 y	DO	Before surgery	Total movement (°)* Skeletal movement (°)* Occlusal plane (°)* Vertical bone loss (mm)* Transversal bone loss (mm)* Apical base enlargement (mm)* Alveolar process enlargement (mm)*	B
El-Bialy et al., 2013[11]	Prospective clinical study	10 patients 7 M, 3 F Mean age 24.7 y	DO	Before surgery	SNA (°)*; SNB (°)*; ANB (°)*; MPA (°)*; Go–Gn (mm)*; Cd–Gn (mm)*; Na–Me (mm)*; LAFH (%)*; LAFH (ANSMe) (mm)*; L1/MPA (°)*; LADH (mm)*; LPDH (mm)*; LL–E line (mm)*	B
Joss et al., 2013[17]	Retrospective study	17 patients 3 M, 14 F Mean age: 29.8 y	DO	Before surgery	Age/Pog′ y-values ($R = 0.538$)* Age/Pog′ x-values ($R = -0.512$)* Age/labrale inferior x-values ($R = -0.492$)* B-point x-values/labrale inferior y-values ($R = -0.637$)* B-point x-values/stomion inferior ($R = -0.561$)* NL–ML′ (°)/labrale inferior x-values ($R = 0.494$)* B-point x-values/B′-point x-values ($R = 0.569$–0.681)* Incision inferior x-values/labrale inferior x-values ($R = 0.422$–0.649)* Incision inferior/labrale superior ($R = 0.454$–0.592)*	B

Table 4 (*Continued*)

Author, year	Study design	Population Sex Age	Intervention	Comparison	Significant outcomes[a]	SBU grade
Joss et al., 2013[18]	Retrospective study	17 patients 3 M, 14 F Mean age 29.8 y	DO	Before surgery	Mandibular advancement (B-point, ASAB, incision inferior)** Gonial angle/Pog *x*-values ($R = 0.544$)* NL–ML′ (°)/B *x*-value relapse ($R = 0.576$–0.633)* NL–ML′ (°)/Pog *x*-value relapse ($R = 0.588$–0.773)** NSL–ML′ (°)/B *x*-value relapse ($R = 0.487$)* NSL–ML′ (°)/Pog *x*-value relapse ($R = 0.596$)* Jarabak ratio/B *x*-value relapse ($R = -0.538$)* Jarabak ratio/Pog *x*-value relapse ($R = -0.586$)*	B

SBU, Swedish Council on Technology Assessment in Health Care; M, male; F, female; y, years; m, months; T0, baseline; T1, immediately after distraction osteogenesis; DO, distraction osteogenesis; SNB, sella–nasion–B-point angle; ANB, A-point–nasion–B-point angle; Wits, Wits value; SpP/MP, palatal plane–mandibular plane angle; LMS; Pg/Pgs; SNA, sella–nasion–A-point angle; MPA, mandibular plane angle; Go–Gn, gonion–gnathion; Cd–Gn, condylion–gnathion; Na–Me; LAFH, lower anterior facial height; ANSMe; IMPA; LADH, lower anterior dental height; LPDH, lower posterior dental height; LL–E line, lower lip–aesthetic line; NL–ML, nasal line–mandibular line angle; ASAB, alveolar surgical anterior base point; NSL–ML, nasion–sella line–mandibular line angle.

[a] Significant outcomes: *$P < 0.05$; **$P < 0.001$.

Miscellaneous

In both studies reported in 2004, Breuning et al. observed a significant decrease of 1.2 mm for overbite.[12,13] A decrease of 4.4 mm for overjet was reported in only one study. Comparing phase 1 and phase 2 treatment with phase 2 treatment only, a significant difference in duration of therapy was recorded (15.6 months, $P < 0.01$).

Metzler et al. observed a significant transversal bone loss of 3.9 mm ($P < 0.01$).[16]

El-Bialy et al. observed an increase in lower incisor–mandibular plane angle (L1/MPA) after MDO (T1–T2 7.9°) and a significant decrease after debonding and at follow-up (T2–T3 −14.7°, T1–T4 −7.5°, T2–T4 −15.4°).[11] Lower anterior dental height (LADH) and lower posterior dental height (LPDH) increased both at the end of MDO and at follow-up (LADH (mm): T1–T2 1.3, T1–T4 2.8, T2–T4 1.5; LPDH (mm): T1–T2 2.7, T1–T4 2.5) ($P < 0.05$).

Discussion

The present systematic review analyzed the skeletal and soft tissue effects of MDO. Both retrospective and prospective studies were included in the review process. Despite the widespread use of MDO, there is still a lack of strong evidence regarding the immediate and long-term effects on the bones and soft tissues. According to the SBU tool, the evidence emerging from the selected papers is of a limited level. The main limitations found in all of the C grade studies were the absence of information on the randomization procedures, the lack of adequate blinding procedures, and method error analysis. Therefore, the results should be interpreted with caution; conclusions with a limited level of evidence can be drawn from this review process.

A meta-analysis of the results of the studies was planned. However, due to the high heterogeneity ($I^2 > 75\%$), a meta-analysis was not performed, as suggested by the Cochrane Collaboration.[19]

Since the first publication on MDO in 1977,[20] no systematic review has focused directly on evaluating the effects of MDO on the basal bones and soft tissues.

Vertical and sagittal skeletal dimensions increased significantly, by a mean of 5–10 mm ($P < 0.05$) and 5–8 mm (10% mandible length) ($P < 0.05$), respectively. Improvements were recorded for angular measurements in both planes as well. However, a considerable relapse occurred, especially in the vertical plane (2.5 mm). These results are slightly worse than those presented by Ow et al. in 2009, who stated a mean relapse of around 11–20%.[21] The results of the present review suggest that some variables, such as a high gonial angle and the Jarabak ratio, are correlated with an increase in relapse. Ow et al. investigated the correlation between the mandibular plane angle and bilateral sagittal split osteotomy (BSSO) relapse only, registering a significant increase in skeletal relapse for high values of mandibular plane angle.[21] Furthermore, larger values of cranial divergence seem to have an impact on the relapse, resulting in more consistent changes.

Very little evidence is available regarding the soft tissue vertical dimension, while for sagittal positioning of the lips and surrounding structures, a 90% correspondence between skeletal and soft tissue cephalometric points was observed by various authors.[14,17] Dental-to-soft tissue agreement was stated to be around 20%. These results are slightly lower than those presented by Joss et al.; they evaluated the soft tissue response after BSSO, observing a 100% correspondence for skeletal modifications and a 30% correspondence for dental ones.[5]

Furthermore, as stated by El-Bialy et al.,[11] the strong associations between the changes in lower incisor inclination to mandibular plane angle and lower lip position relative to the E-plane confirm the effects of MDO on lip profile aesthetics, showing the importance of lower incisor position for this facial feature.[22,23]

Among the miscellaneous factors analyzed, a significant decrease in overjet at long-term follow-up confirms the effectiveness of correction with MDO.[12,13] Increases in the dental posterior and

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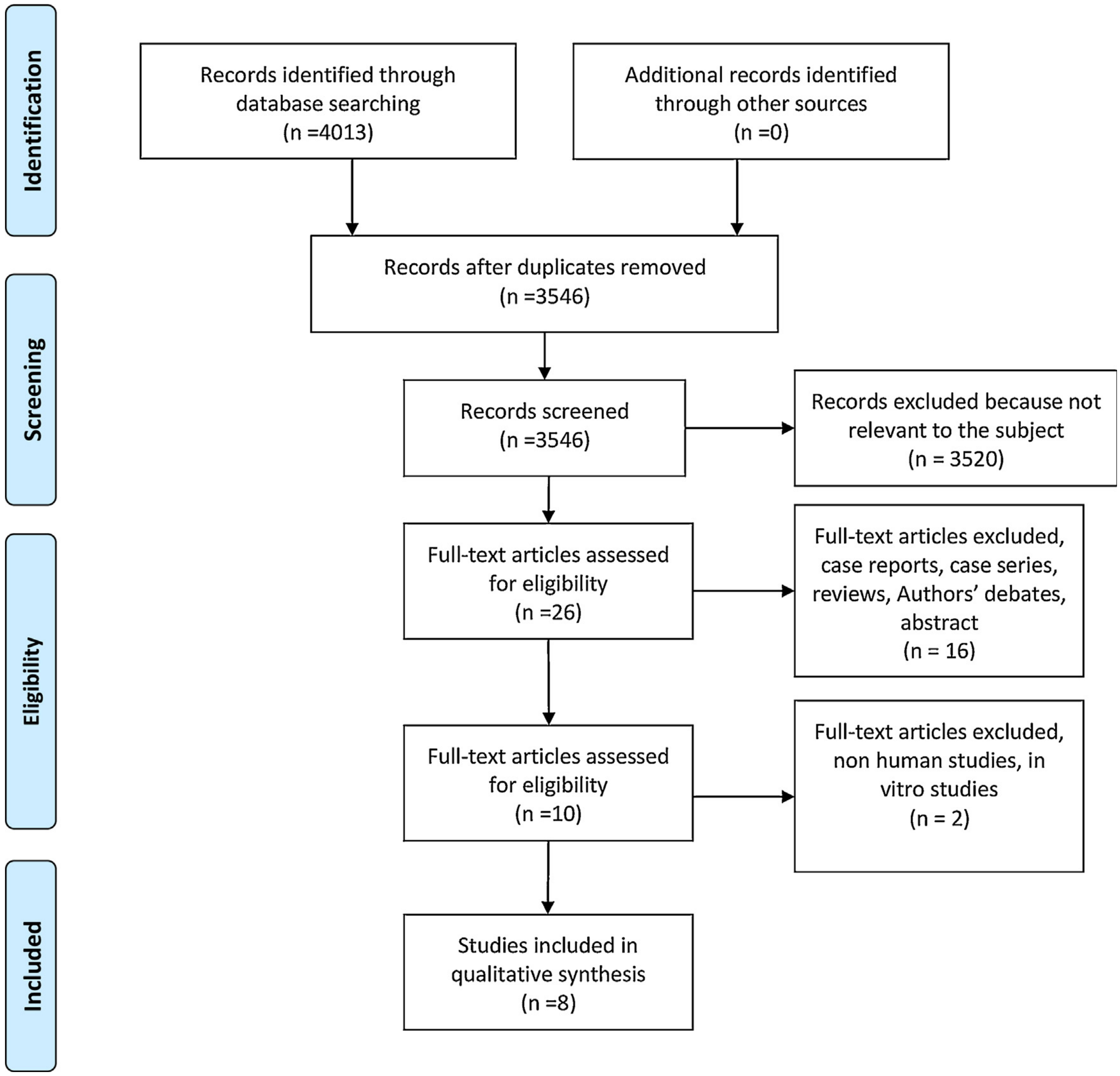

Fig. 1. Flow chart according to the PRISMA statement.

anterior heights were reported[11]; these were probably due to the extrusive effect of fixed orthodontic appliances and not to the surgical technique itself.

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Competing interests

Nothing to declare.

Ethical approval

Not required.

Patient consent

Not required.

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