Int. J. Oral Maxillofac. Surg. 2019; xxx: xxx–xxx
https://doi.org/10.1016/j.ijom.2019.02.022, available online at https://www.sciencedirect.com

International Journal of Oral & Maxillofacial Surgery

Systematic Review
Orthognathic Surgery

Evaluation of long-term hard tissue remodelling after skeletal class III orthognathic surgery: a systematic review

L. Gaitán Romero[1,2], D. Mulier[1,2], K. Orhan[1,2,3], S. Shujaat[1,2], E. Shaheen[1,2], G. Willems[4], C. Politis[1,2], R. Jacobs[1,2,5]

[1]OMFS IMPATH Research Group, Department of Imaging and Pathology, Faculty of Medicine, KU Leuven, Leuven, Belgium; [2]Department of Oral and Maxillofacial Surgery, University Hospitals Leuven, Leuven, Belgium; [3]Ankara University Faculty of Dentistry, Department of Dentomaxillofacial Radiology, Ankara, Turkey; [4]Department of Oral Health Sciences — Orthodontics, KU Leuven and Dentistry, University Hospitals Leuven, Leuven, Belgium; [5]Department of Dental Medicine, Karolinska Institutet, Stockholm, Sweden

L. Gaitán Romero, D. Mulier, K. Orhan, S. Shujaat, E. Shaheen, G. Willems, C. Politis, R. Jacobs: Evaluation of long-term hard tissue remodelling after skeletal class III orthognathic surgery: a systematic review. Int. J. Oral Maxillofac. Surg. 2019; xxx: xxx–xxx. © 2019 International Association of Oral and Maxillofacial Surgeons. Published by Elsevier Ltd. All rights reserved.

Abstract. This systematic review was performed to investigate the long-term hard tissue stability in orthognathic surgery patients with skeletal class III malocclusion. A literature search was conducted using the Embase, Cochrane Central, Web of Science, and PubMed databases, yielding 3690 articles published up to June 2018. Nine articles met the inclusion criteria; these reported skeletal changes in 886 patients with between 5 and 12.7 years of follow-up. Risk of bias was assessed according to the Cochrane Handbook. Results showed variations in stability based on age, facial pattern, surgical procedure, and fixation type. Young patients showed a greater increase in mandibular length and higher A-point stability after bimaxillary surgery than older patients. Dolichofacial patients showed skeletal relapse with a facial clockwise rotation, whereas counterclockwise rotation was observed in brachyfacial patients. Single mandibular setback surgery was linked to stability loss with decreased mandibular ramus and gonion angle; meanwhile, genioplasty fell into the highly stable surgery category. The hyoid bone relapsed significantly postero-inferiorly, which correlated with suprahyoid muscle changes but little to no mandibular position changes. Fixation with monocortical miniplates showed higher patient satisfaction and better stability compared to bicortical screw fixation. These conclusions should be regarded with caution because of the lack of current evidence from three-dimensional imaging.

Key words: stability; relapse; long-term changes; orthognathic surgery; systematic review.

Accepted for publication 28 February 2019

Skeletal class III patients present a set of bone anomalies based on a disharmonious relationship between the cranial bone structures and the maxillofacial complex, or between only the maxillary and mandibular components. This group of anomalies has a higher prevalence in the Asian population than in the white population, implying a strong genetic influence[1–4]. However, the processes of human migration and globalization may lead to other distributions of skeletal class III

 © 2019 International Association of Oral and Maxillofacial Surgeons. Published by Elsevier Ltd. All rights reserved.

Please cite this article in press as: Gaitán L, et al. Evaluation of long-term hard tissue remodelling after skeletal class III orthognathic surgery: a systematic review, *Int J Oral Maxillofac Surg* (2019), https://doi.org/10.1016/j.ijom.2019.02.022

malocclusion. These skeletal anomalies can be treated by maxillary advancement or mandibular setback, which can be performed as a single or combined surgical procedure. Le Fort I osteotomy and bilateral sagittal split osteotomy (BSSO) are the most common surgical procedures used for correcting vertical and sagittal deformities and asymmetries[5–7].

Long-term remodelling is related to multiple adaptations in response to local stimuli such as masticatory function, interdigitation, condylar remodelling in the glenoid cavity, neuromuscular adaptation, orofacial muscle behaviour, and post-surgical fixation method[8–11]. In addition, patient age, surgical experience, type of skeletal pattern, and response to global growth play a role in long-term hard tissue remodelling.

Although several short-term studies have been proposed[12–14], the literature lacks evidence on long-term stability. In the quest for successful treatment outcomes in correcting skeletal deformity, long-tem follow-up is an important aspect for improving clinical practice to achieve facial balance and optimal occlusion. Hence, a systematic search was conducted for long-term evidence of skeletal changes following class III orthognathic surgery.

Materials and methods

The PRISMA guidelines (Preferred Reporting Items for Systematic Reviews) were followed to ensure the transparency and comprehensiveness of this systematic review. A search protocol was specified in advance and registered in PROSPERO (International Prospective Register of Systematic Reviews, reference number CRD42017062647).

The studies included in this review met the criteria established by the PICO approach (patients/population, intervention, comparison, and outcomes): a skeletal class III population; Le Fort I, BSSO, or bimaxillary orthognathic surgery as the intervention; the difference between post-treatment position of the skeletal structures and the position of these structures at long-term follow-up as the comparison; and long-term remodelling of the skeletal structures as the outcome.

Search strategy

The electronic databases were queried using search equations. The search strategy was accomplished with medical subject heading (MeSH) words and synonyms of three concepts related to the orthognathic surgery (osteotomy), outcomes (process assessment, effectiveness, efficacy, relapse, patient satisfaction, predictability), and radiography evaluation methods (cone beam, tomography, cephalometric, radiography). Combinations of controlled vocabulary and free-text terms were designed and applied in the MEDLINE database PubMed (https://www.ncbi.nlm.nih.gov), Web of Science (http://www.webscience.org), Cochrane Central (http://www.cochrane.org), and Embase (https://www.embase.com) (Supplementary Material, Table S1).

Data collection

The electronic databases were searched up until June 2018 with the recommended Embase and MEDLINE filters to identify randomized controlled trials, prospective studies, retrospective studies, and case series with a minimum of 10 patients. The flow diagram of the article selection process is displayed in Fig. 1. The search was restricted to articles written in English.

Study titles and abstracts identified through the electronic searches were screened, and the full texts of the relevant articles were obtained according to the inclusion and exclusion criteria (Table 1). The inclusion criteria captured only the studies published from the year 2000 onwards, which encompassed studies using rigid fixation; before that time, most evidence concentrated on only wire fixation during orthognathic surgery.

Quality assessment

The evaluation of risk of bias was performed according to the *Cochrane Handbook for Systematic Reviews of Interventions*. Two authors independently performed this assessment. A judgement was expressed regarding 'low risk', 'high risk', or 'unclear risk' for different categories of bias (selection bias, performance bias, detection bias, attrition bias, and reporting bias) (Table 2).

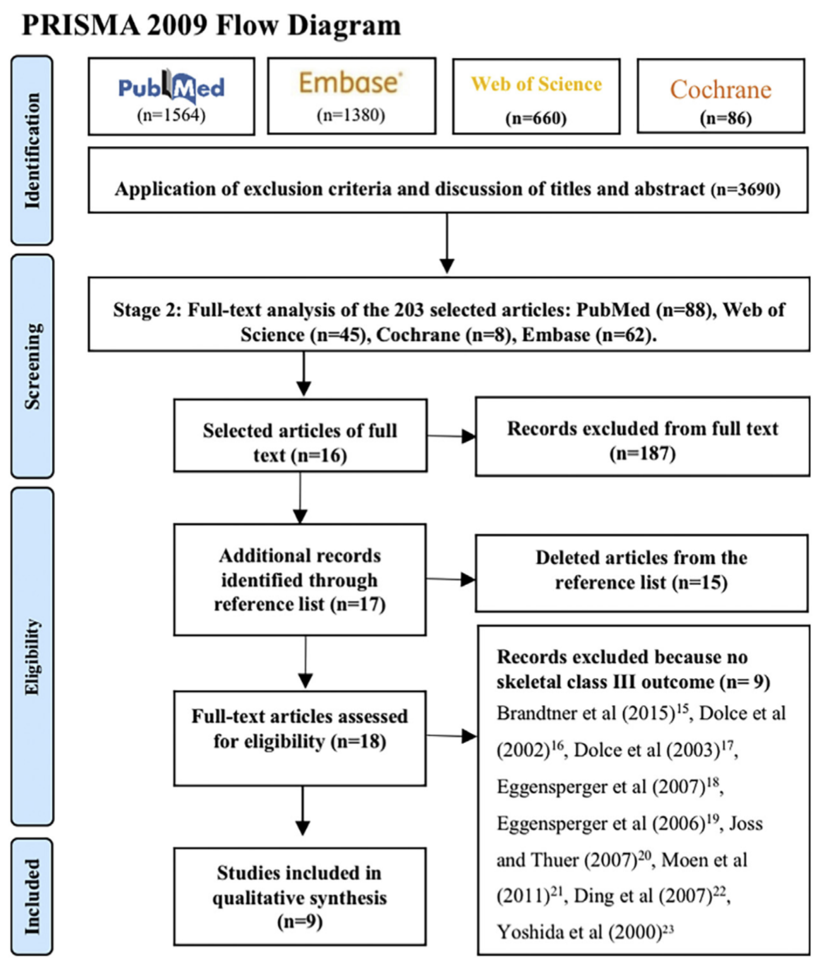

Fig. 1. PRISMA flow diagram of the article selection process.

Please cite this article in press as: Gaitán L, et al. Evaluation of long-term hard tissue remodelling after skeletal class III orthognathic surgery: a systematic review, *Int J Oral Maxillofac Surg* (2019), https://doi.org/10.1016/j.ijom.2019.02.022

Table 1. Inclusion and exclusion criteria.

	Inclusion criteria	Exclusion criteria
Study design	RCTs, prospective and retrospective cohort studies, and case series with >10 patients	Case reports, case series with <10 patients, opinion articles, review articles, animal or in vivo studies
Participants	Patients with skeletal malocclusion who underwent combined orthodontic and orthognathic surgery treatment	Patients with genetic or systemic diseases, craniofacial anomalies, previous facial trauma, previous maxillofacial surgery
Follow-up period	≥5 years	<5 years
Outcome measures	Skeletal class III changes using a standardized protocol	Non-skeletal changes described
Publication year	Starting from year 2000	Before year 2000
Fixation method	Rigid internal fixation	Other types of fixation (for example, wire fixation)

RCT, randomized clinical trial.

Table 2. Assessment of bias risk.

Reference	Random sequence generation (Selection bias)	Allocation concealment (Selection bias)	Blinding of participants and personnel (Performance bias)	Blinding of outcome assessment (Detection bias)	Incomplete outcome (Attrition bias)	Selective reporting (Reporting bias)
Aydemir et al., 2015[24]	Medium	Medium	Low	Low	Medium	Low
Bailey et al., 2007[26]	Medium	Medium	Medium	Low	Medium	Low
Bailey et al., 2008[25]	Medium	Medium	Medium	Low	Low	Low
Eggensperger et al., 2005[27]	Medium	Medium	Medium	Low	High	Low
Eggensperger et al., 2005[28]	Medium	Medium	Medium	Medium	High	Low
Gallego-Romero et al., 2012[29]	Medium	Medium	Medium	Low	High	High
Joss and Thuer, 2008[30]	Medium	Medium	Low	Low	Low	Low
Proffit et al., 2007[31]	Medium	Medium	Medium	Low	Medium	Medium
Yamashita et al., 2011[32]	Medium	Medium	Medium	Low	Medium	Low

Data extraction

Two authors independently extracted relevant data, including information on the following parameters: patient characteristics, methodological analysis, and treatment (Supplementary Material, Table S2). Disagreements were resolved by subsequent discussion. Numerical results were considered for the evaluation of long-term skeletal remodelling (follow-up >5 years) in light of the occurrence of relapse in skeletal class III patients.

Results

Description of studies

After the screening of titles and abstracts of 3690 papers, 203 potentially eligible articles were selected (Fig. 1). Of these, 187 were excluded for the following reasons: case series with fewer than 10 patients, literature review, and follow-up of less than 5 years. After screening of the reference lists of relevant studies, 17 additional records were identified, of which 15 articles were removed after full-text reading. A total of 18 full-text articles were assessed for eligibility, of which eight were excluded because they did not report on skeletal class III outcomes[15–22]; another article was considered for exclusion because of intermaxillary wire fixation but was taken into consideration for analysis of the growth pattern[23]. Finally, nine articles published between 2005 and 2015 were included for qualitative synthesis[24–32]. All except one provided radiographic evidence of jaw bone remodelling[32]; the exception was focused on long-term changes in the temporomandibular joint (TMJ). In general, two-dimensional lateral projection with profile cephalometric analysis was used; however, only four articles took into account the natural head position while performing cephalometric radiography[24,26,30,31].Furthermore, most of the articles used the anterior cranial base as the reference line, which is essential when combining the results. In total, these publications presented outcome data for 886 patients who had undergone orthodontic and surgical treatment, with a follow-up of 5 to 12.7 years.

Further details related to the included studies are summarized in the Supplementary Material (Table S2).

Results of the qualitative analysis

Table 3 illustrates the main skeletal outcomes of the long-term follow-up after orthognathic surgery in skeletal class III patients. The results indicated better stability in patients after mandibular setback in comparison with patients after mandibular advancement. The class III findings showed a decrease in maxillary advancement and sagittal increase of the mandible in the forward direction, which were the

Please cite this article in press as: Gaitán L, et al. Evaluation of long-term hard tissue remodelling after skeletal class III orthognathic surgery: a systematic review, *Int J Oral Maxillofac Surg* (2019), https://doi.org/10.1016/j.ijom.2019.02.022

Table 3. Review of main skeletal changes at long-term follow-up after orthognathic surgery.

Reference	Jaw involved	Relapse	Long-term skeletal outcomes ≥5 years
Aydemir et al. (2015)[24]	Bimaxillary	–	NS
Bailey et al. (2007)[26]	UJ	+	After Mx advancement, Mx decrease*
	LJ		Male: After Mx advancement, increase SNB*
	LJ		Mx advancement and Md setback group: MPA increased in one-third of the patients
Bailey et al. (2008)[25]	UJ	+	Downward and backward*: older more than younger patients
			Sagittal A-point stable in 90% of the younger patients with LJ ← or bimaxillary
	LJ		Most patients showed forward movements; down movement occurred in older groups with Mx surgery
			Upward movements occurred in young LJ or bimaxillary surgery groups
Eggensperger et al. (2005)[27]	LJ	+	Downward*
	Hyoid + lower	–	Change in hyoid bone position correlated weakly with LJ changes
	Hyoid + muscle	+	Suprahyoid muscle correlated with hyoid remodelling*
Eggensperger et al. (2005)[28]	LJ	+	Change in gonial angle*; decrease in Md ramus and Md body length
Gallego-Romero et al. (2012)[29]	UJ	–	Sagittal relapse NS
	LJ	+	Ramus plane, Md angle, and Md plane*
	Bimaxillary	+	Posterior and vertical movement = dolichofacial rotation pattern
Joss and Thuer (2008)[30]	LJ	+	Change in males was not the same as that in females
			There was a correlation between sex and SNB
			Change in B-point* 15%; change in point Pog 21%
			Three patients showed 100% relapse
			Stability of Md setback was greater than that of Md advancement
Proffit et al. (2007)[31]	Bimaxillary	+	Skeletal class III less relapse than skeletal class II
Yamashita et al. (2011)[32]	LJ	+	TMJ sounds and deviation
			Greater with bicortical screws than with monocortical miniplates
			Miniplates associated with an increase in patient satisfaction
			Surgery complications led to an increase in relapse

LJ, lower jaw; ←, mandibular setback; Md, mandible; MPA, mandibular plane angle; Mx, maxilla; NS, non-significant; Pog, pogonion; SNB, sella–nasion–B-point angle; TMJ, temporomandibular joint; UJ upper jaw. Statistically significant results are indicated with an asterisk (*).

most significant changes. However, facial rotation varied; some patients relapsed clockwise, while others had an anterior rotation.

The changes after orthognathic surgery were also age-dependent. Young patients presented a greater increase in mandibular length and had a stable vertical and horizontal A-point following mandibular surgery. An increase in mandibular plane angle after mandibular surgery was found to be less age-dependent. The outcomes revealed decreasing changes in the ramus after a single mandibular setback surgery at long-term follow-up. Remodelling of the hyoid bone position after orthognathic surgery was associated with suprahyoid muscle changes; however, hyoid bone position changes were not correlated with changes in mandibular position. Patients with bicortical screw fixation more often presented TMJ sounds and deviations during opening and closing movements compared to patients with monocortical screw and miniplate fixation. Furthermore, patient satisfaction was higher after the use of monocortical screws and miniplates and they suffered fewer complications following surgery.

Table 4 shows the sagittal and vertical skeletal changes in millimetres at long-term follow-up in the upper jaw after combined orthodontics and orthognathic surgery treatment in class III patients. In the sagittal plane, A-point relapsed backwards in young and old patients after single maxillary advancement, and

Table 4. Sagittal and vertical skeletal changes at long-term follow-up in the upper jaw after combined orthodontics and orthognathic surgery treatment.

Reference	Plane	Parameter (mm)	Surgery type	Long-term skeletal changes ≥5 years (mm)	Movement
Bailey et al. (2008)[25]	Sagittal	Point A	Young patients UJ →	Δ −0.9 ± 1.88	Backward
			Old patients UJ →	Δ −0.8 ± 2.01	Backward
			LJ ← or bimaxillary (young)	Δ −0.1 ± 1.29	Backward
			LJ ← or bimaxillary (old)	Δ −0.8 ± 2.43	Backward
Joss and Thuer (2008)[30]			LJ ←	Δ 0.94 ± 2	Forward
Aydemir et al. (2015)[24]	Vertical		Bimaxillary	Δ 0.37	Upward
Bailey et al. (2008)[25]			Young patients UJ →	Δ −1.3 ± 2.48	Downward
			Old patients UJ →	Δ −3.0 ± 3.35	Downward
			LJ ← or bimaxillary (young)	Δ −0.5 ± 1.73	Downward
			LJ ← or bimaxillary (old)	Δ −0.9 ± 1.80	Downward

UJ, upper jaw; →, maxillary advancement; LJ, lower jaw; ←, mandibular setback.

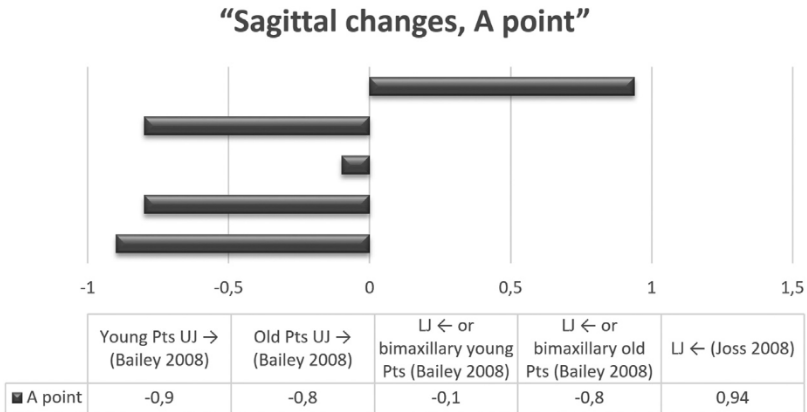

Fig. 2. Sagittal changes in A-point (millimetres) at long-term follow-up.

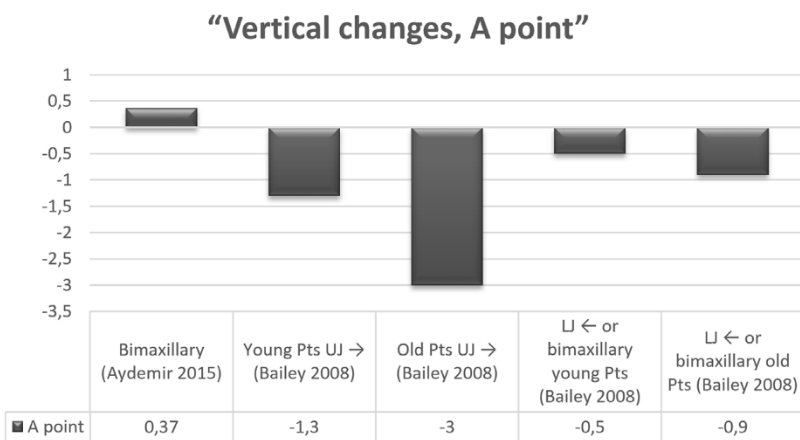

Fig. 3. Vertical changes in A-point (millimetres) at long-term follow-up.

following bimaxillary surgery with maxillary advancement and mandibular setback. Young patients had the most prominent movement backwards after a single maxillary advancement of −0.9 mm. Young patients presented the smallest sagittal relapse of −0.1 mm in comparison to old patients with −0.8 mm following bimaxillary surgery or single maxillary advancement. Fig. 2 shows the backwards displacement of A-point in the sagittal dimension. Nevertheless, the data revealed some maxillary relapse in the forward direction.

Figure 3 illustrates the vertical changes in the A-point landmark, which relapsed to a downward direction in single and combined surgery, with values from −0.5 mm to −3.0 mm in both young and old patients. At the same time, A-point relapsed 0.37 mm upward following bimaxillary surgery.

Table 5 shows the sagittal and vertical angular skeletal changes at a long-term follow-up in the upper jaw. The angle formed between the anterior cranial base (sella–nasion (SN)) and A-point indicated both forward and backward movements, with higher values for backward movements (−1.63°) in dolichofacial patients who underwent bimaxillary surgery (Fig. 4). The palatal plane angle was often decreased in young and old patients with single and combined surgery. The most prominent relapse of the palatal plane (−2.6°) was seen in old patients with single maxillary surgery, in contrast to dolichofacial patients with bimaxillary surgery, for whom this angle increased (0.82°), indicating downward displacement.

Table 6 illustrates the sagittal skeletal changes in millimetres at long-term follow-up in the lower jaw after combined orthodontics and orthognathic surgery treatment. These changes can be interpreted as a trend towards forward movement because B-point, pogonion, gonion, and menton relapsed in the forward direction in most of the cases. The mandibular length (condylion–pogonion) showed forward relapse in both young and old patients.

Table 7 shows the angular sagittal skeletal changes after combined orthodontics and orthognathic surgery treatment. B-point mostly showed forward mandibular relapse in reference to the anterior cranial base (SN). Figs. 5 and 6 represent data values of the mostly forward changes,

Table 5. Sagittal and vertical angular skeletal changes at long-term follow-up in the upper jaw after combined orthodontics and orthognathic surgery treatment.

References	Plane	Parameter (°)	Surgery type	Long-term skeletal changes ≥5 years (°)	Movement
Aydemir et al. (2015)[24]	Sagittal	SNA	Bimaxillary	Δ 0.75	Forward
Bailey et al. (2007)[26]			UJ →	Δ 0.00 ± 1.24	Forward
			LJ ←	Δ −0.22 ± 0.91	Backward
			Bimaxillary	Δ −0.18 ± 1.20	Backward
Gallego-Romero et al. (2012)[29]			Bimaxillary	Δ −1.63 ± 2	Backward
Joss and Thuer (2008)[30]			LJ ←	Δ 0.68 ± 1.7	Forward
Bailey et al. (2008)[25]	Vertical	Palatal plane	Young patients UJ →	Δ −1.6 ± 4	Upward
			Old patients UJ →	Δ −2.6 ± 3.52	
			LJ ← or bimaxillary (young)	Δ −0.8 ± 2.08	
			LJ ← or bimaxillary (old)	Δ −0.6 ± 2.31	
Gallego-Romero et al. (2012)[29]			Bimaxillary	Δ 0.82 ± 1.66	Back–down

SNA, sella–nasion–A-point; UJ, upper jaw; →, maxillary advancement; LJ, lower jaw; ←, mandibular setback.

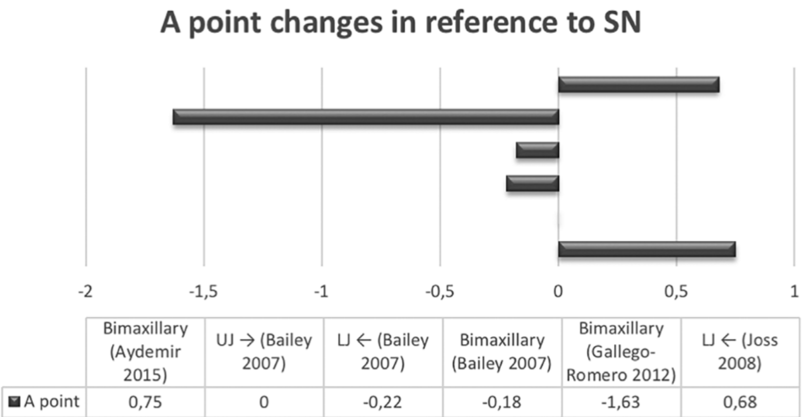

Fig. 4. A-point changes in reference to SN (sella–nasion) at long-term follow-up.

together with backward sagittal changes of B-point. Furthermore, an intermaxillary discrepancy was observed in two studies, which had different relapse at long-term follow-up: one was a significant −1.95°, indicating a more anterior mandibular position in relation to the maxillary position, and the other was a change of 0.38°, which was not significant.

Table 8 displays the vertical skeletal changes in the cephalometric landmarks at long-term follow-up for the mandible. Both pogonion and menton showed relapse in the upward and downward directions. In general, the shortening of ramus height was represented by a relapse of the gonion point in the upward direction. The hyoid bone relapsed significantly postero-inferiorly after combined orthodontics and orthognathic surgery treatment. B-point mostly showed vertical and downward movement; however, an upward movement was also noted (Fig. 7).

The vertical angular skeletal changes at long-term follow-up are displayed in Table 9. The decreasing changes in the mandibular plane angle had higher values than the increasing values of the mandibular plane angle. However, gonion angle increased, indicating back–down rotation of the mandibular plane and/or inclination of the ramus. In dolichofacial patients, gnathion relapsed backwards in reference to SN, and gonion–gnathion rotated back down.

Risk of bias within studies

Based on the Cochrane risk of bias tool, a high risk was observed for three studies. One of the studies showed attrition and reporting bias, because of case elimination with little dental stability[29]. The other two articles had only 38% of the total patients available for long-term evaluation, leading to a high risk of attrition bias[27,28]. Furthermore, there was a 100% moderate risk of selection bias in all nine articles because of the lack of patient randomization[24–32]. Most of the selected articles reported retrospective cohort studies, except for one with a prospective nature[30]. The risk of performance bias was low in 22% and moderate in 78%. Detection bias was low in 89% and moderate in 11%. Attrition bias was low risk in 22%, moderate in 44%, and high in 33%. Finally, 78% had a low risk of reporting bias, 11% had a moderate risk, and 11% had a high risk (Fig. 8).

Table 6. Sagittal skeletal changes at long-term follow-up in the lower jaw after combined orthodontics and orthognathic surgery treatment.

References	Plane	Parameter (mm)	Surgery type	Long-term skeletal changes ≥5 years (mm)	Movement
Aydemir et al. (2015)[24]	Sagittal	B	Bimaxillary	Δ 1.91	Forward
Bailey et al. (2008)[25]		B	Young patients UJ →	Δ 3.0 ± 3.31	Forward
		Pog		Δ 3.5 ± 4.72	Forward
		Co–Pog		Δ 2.1 ± 3.26	Forward
		B	Old patients UJ →	Δ 4.0 ± 3.36	Forward
		Pog		Δ 4.9 ± 4.03	Forward
		Co–Pog		Δ 0.7 ± 1.46	Forward
		B	LJ ← or bimaxillary (young)	Δ 3.1 ± 2.21	Forward
		Pog		Δ 3.2 ± 2.29	Forward
		Co–Pog		Δ 2.4 ± 2.39	Forward
		B	LJ ← or bimaxillary (old)	Δ 2.5 ± 3.50	Forward
		Go		Δ 3.0 ± 4.29	Forward
		Pog		Δ 3.0 ± 3.50	Forward
		Co–Pog		Δ 2.0 ± 3.43	Forward
Eggensperger et al. (2005)[27]		B	LJ ←	Δ 0.1 ± 3.4	Forward
		Pog		Δ −0.2 ± 4.5	Backward
		Hyoid	LJ ←	Δ 0.9 ± 6.9	
Eggensperger et al. (2005)[28]		B	LJ ←	Δ 1 ± 2.8	Forward
		Pog	LJ ←	Δ 0.9 ± 3.2	Forward
		Me	LJ ←	Δ 1.6 ± 3.3	Forward
		Go	LJ ←	Δ 1 ± 3.6	Forward
Joss and Thuer (2008)[30]		B	LJ ←	Δ 0.94 ± 2.34	Forward
		Pog	LJ ←	Δ 1.46 ± 2.86	Forward
		Go	LJ ←	Δ 2.28* ± 3.88	Forward

B, B-point; Co, condylion; Go, gonion; Pog, pogonion; UJ, upper jaw; →, maxillary advancement; LJ, lower jaw; ←, mandibular setback. Statistically significant results are indicated with an asterisk (*).

Please cite this article in press as: Gaitán L, et al. Evaluation of long-term hard tissue remodelling after skeletal class III orthognathic surgery: a systematic review, *Int J Oral Maxillofac Surg* (2019), https://doi.org/10.1016/j.ijom.2019.02.022

Table 7. Sagittal angular skeletal changes at long-term follow-up in the lower jaw after combined orthodontics and orthognathic surgery treatment.

References	Plane	Parameter (°)	Surgery type	Long-term skeletal changes ≥5 years (°)	Movement
Aydemir et al. (2015)[24]	Sagittal	SNB	Bimaxillary	Δ 0.06	Forward
Bailey et al. (2007)[26]			UJ →	Δ 0.37* ± 1.16	Forward
			LJ ←	Δ −0.08 ± 0.84	Backward
			Bimaxillary	Δ −0.19 ± 1.23	Backward
Eggensperger et al. (2005)[28]			LJ ←	Δ 0.4 ± 1.2	Forward
Joss and Thuer (2008)[30]			LJ ←	Δ 0.31 ± 1.17	Forward
Gallego-Romero et al. (2012)[29]			Bimaxillary	Δ 0.32 ± 1.52	Forward
Joss and Thuer (2008)[30]		ANB	Bimaxillary	Δ −1.95* ± 1.09	Relapse
			LJ ←	Δ 0.38 ± 1.51	Relapse

ANB, A-point–nasion–B-point; SNA, sella–nasion–A-point; UJ, upper jaw; →, maxillary advancement; LJ, lower jaw; ←, mandibular setback. Statistically significant results are indicated with an asterisk (*).

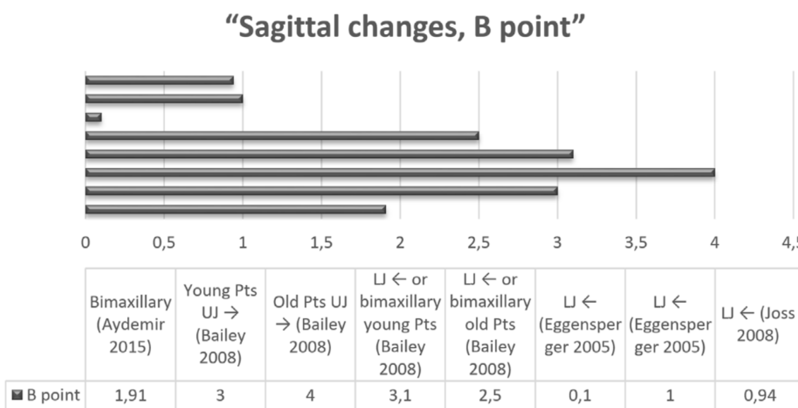

Fig. 5. Sagittal changes in B-point (millimetres) at long-term follow-up.

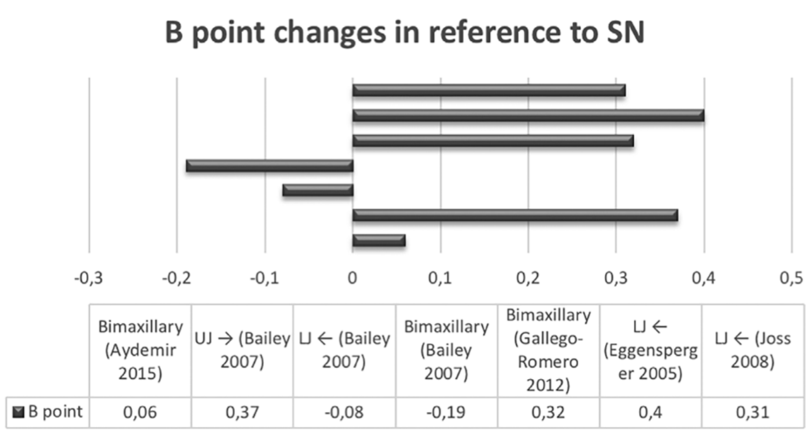

Fig. 6. B-point changes in reference to SN (sella–nasion) at long-term follow-up.

Discussion

This article provides information on long-term hard tissue remodelling after orthognathic surgery in skeletal class III patients from the USA, Europe, and Asia, adding to evidence of the global and long-term morphological changes around the world. The outcomes also revealed trends in bimaxillary surgical techniques for skeletal class III patients in recent years, because of the secure placement of the condyle in the mandibular fossa during this type of surgery. This surgery resulted in higher stability and decreased occlusal forces compared to the single mandibular setback technique[30,31,33,34]. Furthermore, single mandibular surgery showed unstable counterclockwise rotation following the correction of anterior open bite[22]. Therefore, study of the surgical technique and its limitations is essential. Also, the fixation technique can affect the long-term stability associated with decreased stability of the class III patients during the first few years post-surgery[31].

This systematic review included five articles with long-term outcomes of bimaxillary surgery[24–26,29,31]. In the other four articles, single surgery with mandibular setback was investigated[27,28,30,32]. When comparing the two types of osteotomies and surgical outcomes, a higher rate of relapse was observed for single-jaw surgery; the outcomes showed that the mean surgical osteotomy displacement was more prominent in the single setback surgery compared to bimaxillary surgery, with shorter bone displacement. Additionally, hyoid bone and airway size suffered relapse after single-jaw surgery. The upper, middle, and lower pharyngeal airway sizes were smaller at long-term follow-up than they had been at baseline[27]. Furthermore, patient treatment planning should be based on a balanced amount of osteotomy, taking into consideration the airway and stability of the occlusal plane. The fact that the airway was smaller at long-term follow-up could have been a result of the physiological aging process of the oropharyngeal complex[27,35]. However, the better distribution of the osteotomy in bimaxillary surgery could prevent compression of the airways.

Bimaxillary and single maxillary advancement surgeries were classified as stable surgical techniques. Moreover, genioplasty showed the highest stability,

Please cite this article in press as: Gaitán L, et al. Evaluation of long-term hard tissue remodelling after skeletal class III orthognathic surgery: a systematic review, *Int J Oral Maxillofac Surg* (2019), https://doi.org/10.1016/j.ijom.2019.02.022

Table 8. Vertical skeletal changes at long-term follow-up in the lower jaw after combined orthodontics and orthognathic surgery treatment.

References	Plane	Parameter (mm)	Surgery type	Long-term skeletal changes ≥5 years (mm)	Movement
Aydemir et al. (2015)[24]	Vertical	B	Bimaxillary	Δ −1.52	Upward
Bailey et al. (2008)[25]		B	Young patients UJ →	Δ −0.9 ± 2.45	Downward
		Pog		Δ 0.1 ± 3.82	Upward
		B	Old patients UJ →	Δ −3.2 ± 3.18	Downward
		Pog		Δ −3.4 ± 3.51	Downward
		B	LJ ← or bimaxillary (young)	Δ 0.0 ± 3.31	Upward
		Pog		Δ 0.1 ± 2.71	Upward
		B	LJ ← or bimaxillary (old)	Δ −1.6 ± 2.84	Downward
		Pog		Δ −1.5 ± 2.92	Downward
Eggensperger et al. (2005)[27]		B	LJ ←	Δ 3.9 ± 11.2	Upward
		Pog		Δ 2.0 ± 2.7*	Upward
		Me		Δ 1.3 ± 2.1 *	Upward
		Hyoid	Bimaxillary	Δ −3.3 ± 3.4*	Back–down
Eggensperger et al. (2005)[28]		B	LJ ←	Δ 0.9 ± 3.1	Downward
		Pog	LJ ←	Δ 0.9 ± 2.5	Downward
		Me	LJ ←	Δ 1 ± 2	Downward
		Go	LJ ←	Δ −1.3 ± 2.9	Upward
Joss and Thuer (2008)[30]		B	LJ ←	Δ −1.12 ± 2.5	Upward
		Pog	LJ ←	Δ 1.52* ± 1.93	Downward*
		Go	LJ ←	Δ −1.53 ± 2.66	Upward
		Me	LJ ←	Δ −0.35* ± 1.76	Upward

B, B-point; Go, gonion; Me, menton; Pog, pogonion; UJ, upper jaw; →, maxillary advancement; LJ, lower jaw; ←, mandibular setback. Statistically significant results are indicated with an asterisk (*).

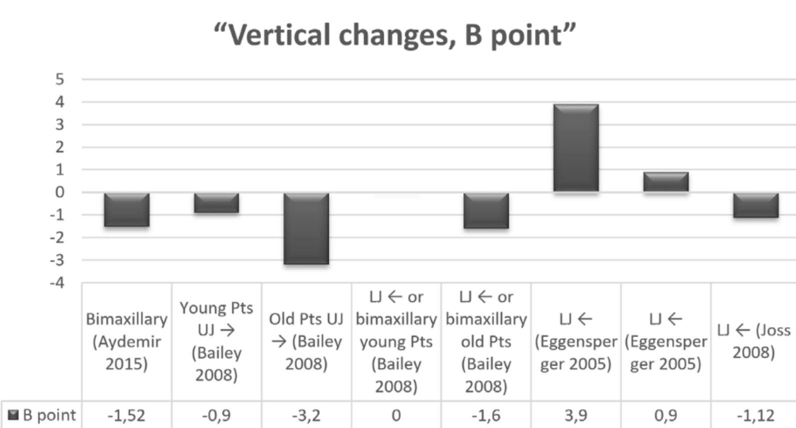

Fig. 7. Vertical changes in B-point (millimetres) at long-term follow-up.

promoting positive symphyseal remodelling[31]. However, single mandibular setback and maxillary expansion surgeries showed a lack of stability. The type of surgery, together with the type of fixation and complications occurring during surgery, contributed towards relapse. An excess intraoperative blood loss and longer surgical time were the complications experienced during bicortical screw fixation. The long-term effects of these complications in several of the patients were TMJ sounds, pain, and midline deviation during mandibular movement[32].

Furthermore, a posterior lack of stretched muscle forces is a factor in relapse. This posterior lack is associated with patient characteristics or the use of severe and prolonged forces during the procedure. The latter helps with rotation and displacement of the condyles and is correlated with adaptation of the fixed fragments and occlusal function[11].

Condylar positional changes and the resorption process influence the general remodelling after surgery, especially the gonial angle. The gonial angle was measured to assess condylar distraction from the fossa, which related to the vertical dimension, influencing mandibular ramus inclination[9,10,28,33]. In addition, excessive rotation of the proximal fragments and an extended operating time might have led to the TMJ problems and increased stress on mandibular movement[32]. These problems must be prevented during planning in order to achieve the correct function. Therefore, the mandibular joint position needs to be examined carefully before surgery because TMJ and occlusal problems could be masked by muscle adaptation[36]. Soft tissue function also plays an essential role in the biological equilibrium, leading to an abnormal position of the hard tissue structures following parafunctional habits such as tongue thrust[22]. Therefore, these parafunctional muscle forces should be treated before surgery to provide better stability of the dentofacial functional complex, also guiding the direction of growth.

The long-term remodelling can be predicted by growth, which is based on the characteristics of each facial pattern and anchorage type. The growth patterns could explain the tendency to relapse in patients with different mandibular rotation and vertical skeletal changes. The growth pattern and direction of mandibular relapse in brachyfacial, mesiofacial, and dolichofacial patients has been documented. The mesiofacial type shows a tendency towards posterior clockwise rotation relapse[23,29]. The brachyfacial type shows counterclockwise rotation with an increase[23], whereas

Table 9. Vertical angular skeletal changes at long-term follow-up in the lower jaw after combined orthodontics and orthognathic surgery treatment.

References	Plane	Parameter (°)	Surgery type	Long-term skeletal changes ≥5 years (°)	Movement
Aydemir et al. (2015)[24]	Vertical	SN/Go–Gn	Bimaxillary	Δ 2.31	Back–down
Bailey et al. (2008)[25]		Md plane	Young patients UJ →	Δ −2.3 ± 2.43	Upward
			Old patients UJ →	Δ −3.0 ± 2.58	
			LJ ← or bimaxillary (young)	Δ 0.1 ± 3	Downward
			LJ ← or bimaxillary (old)	Δ 1.1 ± 2.46	
Eggensperger et al. (2005)[28]		Go	LJ ←	Δ 6.3* ± 5.2	Back–down
Gallego-Romero et al. (2012)[29]		SN/Go–Gn	Bimaxillary	Δ 2.11 ± 1.4	Back–down
		SN/S–Gn		Δ 0.74 ± 1.6	Backward
Joss and Thuer (2008)[30]		Go	LJ ←	Δ 3.45 ± 4.85	Back–down
		SN/Md plane		Δ 1.12 ± 2.34	Downward

SN, sella–nasion (cranial base); Go, gonion; Gn, gnathion; Md, mandibular; S, sella; UJ, upper jaw; →, maxillary advancement; LJ, lower jaw; ←, mandibular setback. Statistically significant results are indicated with an asterisk (*).

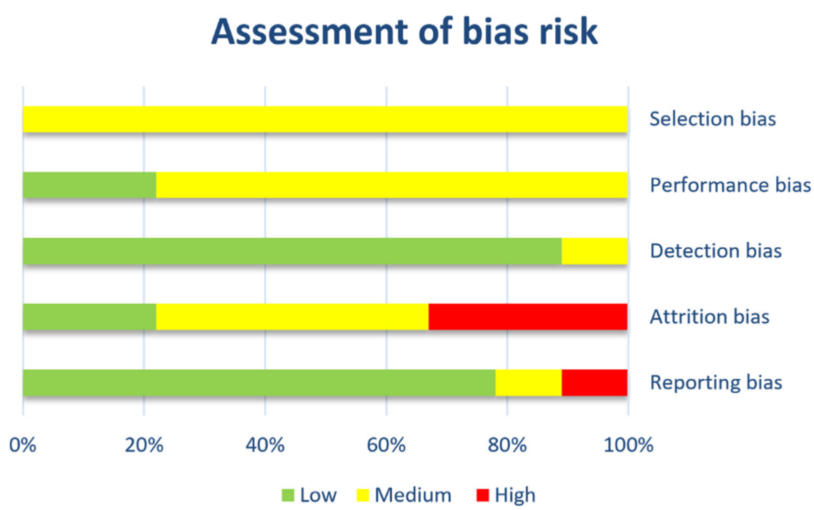

Fig. 8. Assessment of bias risk.

dolichofacial patients show back–downward regular rotation[29] (Fig. 9). Brachyfacial patients usually have a deeper bite and stronger musculature, providing robust natural anchorage with resistance to mandibular rotation. The dolichofacial patients had a more substantial vertical mandibular component with a tendency towards downward posterior rotation and open bite because of the weaker natural anchorage of the muscles[23,29].

In patients with mandibular prognathism, mandibular growth occurred up to older ages (Supplementary Material, Table S2), with a stronger trend for this effect in patients who were younger at the time of surgery[25,31]. However, long-term mandibular growth did not differ between female patients treated before the age of 18 years and males treated before the age of 20 years, compared with patients treated at an older age[30]. Male patients showed a statistically significant forward movement of the sella–nasion–B-point angle after single maxillary advancement surgery, with consequent mandibular remodelling to achieve occlusal stability[30]. Furthermore, sex correlated significantly with relapse; women showed a positive growth direction that influenced the long-term outcome[30].

In conclusion, this systematic review gives a perspective on the factors associated with relapse after orthognathic surgery at long-term follow-up of 5 to 12.7 years. Studies with three-dimensional imaging are required for the assessment of long-term follow-up to optimize treatment planning and improve the predictability of outcomes in skeletal class III patients.

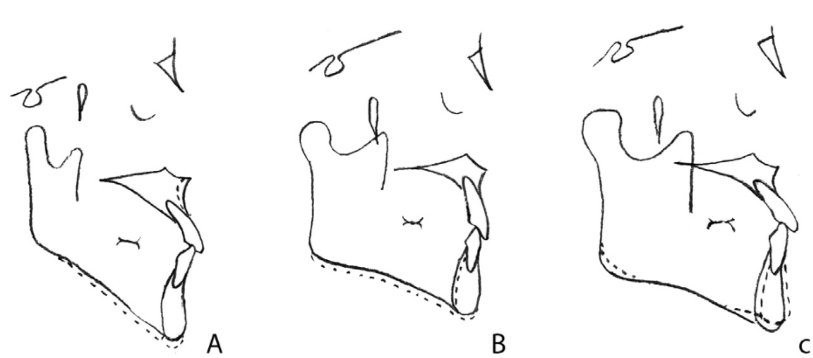

Fig. 9. Skeletal changes at long-term follow-up in (A) dolichofacial patients, (B) mesiofacial patients, and (C) brachyfacial patients.

Funding

None.

Competing interests

There is no competing interest.

Ethical approval

Not required.

Patient consent

Not required.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at https://doi.org/10.1016/j.ijom.2019.02.022.

References

1. Chan GK. Class III malocclusion in Chinese (Cantonese): etiology and treatment. *Am J Orthod* 1974;**65**:152–7. http://dx.doi.org/10.1016/0002-9416(74)90176-6.
2. Yamaguchi T, Park SB, Narita A, Maki K, Inoue I. Genome-wide linkage analysis of mandibular prognathism in Korean and Japanese patients. *J Dent Res* 2005;**84**:255–9. http://dx.doi.org/10.1177/154405910508400309.
3. Emrich RE, Brodie AG, Blayney JR. Prevalence of class I, class II, and class III malocclusions (Angle) in an urban population. An epidemiological study. *J Dent Res* 1965;**44**:947–53. http://dx.doi.org/10.1177/00220345650440053301.
4. Litton SF, Ackermann LV, Isaacson RJ, Shapiro BL. A genetic study of class III malocclusion. *Am J Orthod* 1970;**58**:565–77. http://dx.doi.org/10.1016/0002-9416(70)90145-4.
5. Welch TB. Stability in the correction of dentofacial deformities: a comprehensive review. *J Oral Maxillofac Surg* 1989;**47**:1142–9. http://dx.doi.org/10.1016/0278-2391(89)90003-7.
6. Trauner R, Obwegeser H. Zur Operationstechnik bei der Progenie und anderen Unterkieferanomalien. *Dtsch Zahn Mund Kieferheilkd* 1954;**23**:1–10.
7. Dal Pont G. Retro-molar osteotomy for correction of prognathism. *Minerva Chir* 1959;**14**:1138–41.
8. Reitzik M. Surgically corrected mandibular prognathism. *Am J Orthod* 1974;**66**:82–95. http://dx.doi.org/10.1016/0002-9416(74)90195-X.
9. Franco JE, Van Sickels JE, Thrash WJ. Factors contributing to relapse in rigidly fixed mandibular setbacks. *J Oral Maxillofac Surg* 1989;**47**:451–6. http://dx.doi.org/10.1016/0278-2391(89)90276-0.
10. Gassmann CJ, Van Sickels JE, Thrash WJ. Causes, location, and timing of relapse following rigid fixation after mandibular advancement. *J Oral Maxillofac Surg* 1990;**48**:450–4. http://dx.doi.org/10.1016/0278-2391(90)90229-U.
11. Kundert M, Hadjianghelou O. Condylar displacement after sagittal splitting of the mandibular rami. *J Maxillofac Surg* 1980;**8**:278–87. http://dx.doi.org/10.1016/S0301-0503(80)80115-9.
12. Abrahamsson C, Ekberg EC, Henrikson T, Bondemark L. Alterations of temporomandibular disorders before and after orthognathic surgery. *Angle Orthod* 2007;**77**:729–34. http://dx.doi.org/10.2319/052906-215.
13. Mucedero M, Coviello A, Baccetti T, Franchi L, Cozza P. Stability factors after double-jaw surgery in class III malocclusion. *Angle Orthod* 2008;**78**:1141–52. http://dx.doi.org/10.2319/101807-498.1.
14. Jayaratne YSN, Zwahlen RA, Lo J, Cheung LK. Facial soft tissue response to anterior segmental osteotomies: a systematic review. *Int J Oral Maxillofac Surg* 2010;**39**:1050–8. http://dx.doi.org/10.1016/j.ijom.2010.07.002.
15. Brandtner C, Hachleitner J, Rippel C, Krenkel C, Gaggl A. Long-term skeletal and dental stability after orthognathic surgery of the maxillo-mandibular complex in class II patients with transverse discrepancies. *J Craniomaxillofac Surg* 2015;**43**:1516–21. http://dx.doi.org/10.1016/j.jcms.2015.07.007.
16. Dolce C, Hatch JP, Van Sickels JE, Rugh JD. Rigid versus wire fixation for mandibular advancement: skeletal and dental changes after 5 years. *Am J Orthod Dentofacial Orthop* 2002;**121**:610–9. http://dx.doi.org/10.1067/mod.2002.123341.
17. Dolce C, Hatch JP, Van Sickels JE, Rugh JD. Five-year outcome and predictability of soft tissue profiles when wire or rigid fixation is used in mandibular advancement surgery. *Am J Orthod Dentofacial Orthop* 2003;**124**:249–56. http://dx.doi.org/10.1016/S0889-5406(03)00446-3.
18. Eggensperger NM, Lieger O, Thüer U, Iizuka T. Soft tissue profile changes following mandibular advancement and setback surgery an average of 12 years postoperatively. *J Oral Maxillofac Surg* 2007;**65**:2301–10. http://dx.doi.org/10.1016/j.joms.2007.06.644.
19. Eggensperger N, Smolka K, Luder J, Iizuka T. Short- and long-term skeletal relapse after mandibular advancement surgery. *Int J Oral Maxillofac Surg* 2006;**35**:36–42. http://dx.doi.org/10.1016/j.ijom.2005.04.008.
20. Joss CU, Thuer UW. Stability of the hard and soft tissue profile after mandibular advancement in sagittal split osteotomies: a longitudinal and long-term follow-up study. *Eur J Orthod* 2007;**30**:16–23. http://dx.doi.org/10.1093/ejo/cjm080.
21. Moen K, Wisth PJ, Skaale S, Bøe OE, Tornes K. Dental or skeletal relapse after sagittal split osteotomy advancement surgery? Long-term follow-up. *J Oral Maxillofac Surg* 2011;**69**:e461–8. http://dx.doi.org/10.1016/j.joms.2011.02.086.
22. Ding Y, Xu TM, Lohrmann B, Gellrich NC, Schwestka-Polly R. Stability following combined orthodontic-surgical treatment for skeletal anterior open bite — a cephalometric 15-year follow-up study. *J Orofac Orthop* 2007;**68**:245–56. http://dx.doi.org/10.1007/s00056-007-0632-2.
23. Yoshida K, Rivera GA, Matsuo N, Takaishi M, Inamoto H, Kurita K. Long-term prognosis of BSSO mandibular relapse and its relation to different facial types. *Angle Orthod* 2000;**70**:220–6. http://dx.doi.org/10.1043/00033219(2000)070<0220:LTPOBM>2.0.CO:2.
24. Aydemir H, Efendiyeva R, Karasu H, Toygar-Memikoğlu U. Evaluation of long-term soft tissue changes after bimaxillary orthognathic surgery in class III patients. *Angle Orthod* 2015;**85**:631–7. http://dx.doi.org/10.2319/062214-449.1.
25. Bailey LJ, Phillips C, Proffit WR. Long-term outcome of surgical class III correction as a function of age at surgery. *Am J Orthod Dentofacial Orthop* 2008;**133**:365–70. http://dx.doi.org/10.1016/j.ajodo.2006.04.039.
26. Bailey LJ, Dover AJ, Proffit WR. Long-term soft tissue changes after orthodontic and surgical corrections of skeletal class III malocclusions. *Angle Orthod* 2007;**77**:389–96. http://dx.doi.org/10.2319/0003-3219(2007)077[0389:LSTCAO]2.0.CO:2.
27. Eggensperger N, Smolka W, Iizuka T. Long-term changes of hyoid bone position and pharyngeal airway size following mandibular setback by sagittal split ramus osteotomy. *J Craniomaxillofac Surg* 2005;**33**:111–7. http://dx.doi.org/10.1016/j.jcms.2004.10.004.
28. Eggensperger N, Raditsch T, Taghizadeh F, Iizuka T. Mandibular setback by sagittal split ramus osteotomy: a 12-year follow-up. *Acta Odontol Scand* 2005;**63**:183–8. http://dx.doi.org/10.1080/00016350510019892.
29. Gallego-Romero D, Llamas-Carrera J, Torres-Lagares D, Paredes V, Espinar E, Guevara E, Gutiérrez-Pérez JL. Long-term stability of surgical-orthodontic correction of class III malocclusions with long-face syndrome. *Med Oral Patol Oral Cir Bucal* 2012;**17**:e435–41. http://dx.doi.org/10.4317/medoral.17647.
30. Joss CU, Thuer UW. Stability of hard tissue profile after mandibular setback in sagittal split osteotomies: a longitudinal and long-term follow-up study. *Eur J Orthod* 2008;**30**:352–8. http://dx.doi.org/10.1093/ejo/cjn008.
31. Proffit WR, Turvey TA, Phillips C. The hierarchy of stability and predictability in orthognathic surgery with rigid fixation: an update and extension. *Head Face Med* 2007;**3**:21. http://dx.doi.org/10.1186/1746-160X-3-21.
32. Yamashita Y, Otsuka T, Shigematsu M, Goto M. A long-term comparative study of two rigid internal fixation techniques in terms of masticatory function and neurosensory disturbance after mandibular correction by bilateral sagittal split ramus osteotomy. *Int J Oral Maxillofac Surg* 2011;**40**:360–5. http://dx.doi.org/10.1016/j.ijom.2010.11.017.
33. Proffit WR, Phillips C, Turvey TA. Stability after mandibular setback: mandible-only versus 2-jaw surgery. *J Oral Maxillofac Surg* 2012;**70**:408–14.
34. Joss CU, Thüer UW. Stability of the hard and soft tissue profile after mandibular advance-

ment in sagittal split osteotomies: a longitudinal and long-term follow-up study. *Eur J Orthod* 2008;**30**:16–23.

35. Kobayashi T, Watanabe I, Ueda K, Nakajima T. Stability of the mandible after sagittal ramus osteotomy for correction of prognathism. *J Oral Maxillofac Surg* 1986;**44**:698–702.

36. Ricketts RM. Abnormal function of the temporomandibular joint. *Am J Orthod* 1955;**41**:435–41.

Address:
Lesly Gaitán Romero
OMFS IMPATH Research Group
Department of Imaging and Pathology
Faculty of Medicine
KU Leuven
Campus Sint-Rafaël
Kapucijnenvoer 33
BE-3000 Leuven
Belgium
Tel.: +32 476811454
E-mail: leslygeysen8@gmail.com

Please cite this article in press as: Gaitán L, et al. Evaluation of long-term hard tissue remodelling after skeletal class III orthognathic surgery: a systematic review, *Int J Oral Maxillofac Surg* (2019), https://doi.org/10.1016/j.ijom.2019.02.022