Int. J. Oral Maxillofac. Surg. 2019; 48: 193–202
https://doi.org/10.1016/j.ijom.2018.06.008, available online at https://www.sciencedirect.com

International Journal of Oral & Maxillofacial Surgery

Systematic Review
Orthognathic Surgery

# Condylar changes after orthognathic surgery for class III dentofacial deformity: a systematic review

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*Abstract.* After orthognathic surgery for class II dentofacial deformity, remodelling of the mandibular condyle will take place. In a number of cases, this may evolve towards a phenomenon of condylar resorption. Yet, studies on the occurrence of this complication after the correction of a class III deformity are scarce. A systematic review of the literature was performed with the aim of identifying reports on condylar resorption or remodelling after orthognathic surgery for class III dentofacial deformity. A search of the international databases yielded 12 eligible studies. Eight studies reported some degree of postoperative condylar remodelling, while symptoms of condylar resorption were only described in a limited group of patients. Thus, the literature may show evidence of condylar remodelling after orthognathic treatment of class III patients, and anecdotal reports of condylar resorption exist. The small sample sizes, heterogeneity in methods and outcomes, and use of two-dimensional radiographs indicate the need for updated long-term research. In the future, the use of cone beam computed tomography data for volumetric and morphological condylar analysis in combination with three-dimensional cephalometry may provide the opportunity to further elucidate this phenomenon and better characterize its aetiology.

Key words: orthognathic surgery; condylar remodelling; condylar resorption; class III dentofacial deformity.

Accepted for publication 15 June 2018
Available online 12 July 2018

Structural condylar changes occurring after orthognathic surgery are well described in the literature[1–5]. Mandibular osteotomies, used in single jaw or bimaxillary surgery, initiate an adaptation mechanism in the temporomandibular joint (TMJ). Mandibular osteotomies may often alter the condylar position, which leads to different load distributions in the TMJ. Adaptation mechanisms in the TMJ may trigger bone remodelling with structural changes that may result in an altered shape of the condyle.

Condylar changes following orthognathic surgery have mainly been studied in patients with class II dentofacial deformity[1,2,6–8]. The focus of these studies has mainly been on explaining relapse,

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condylar resorption, or osteoarthrotic changes. In these studies, postoperative condylar structural changes were subdivided into two main categories: an adaptive physiological process called condylar remodelling, and a pathological process called condylar resorption[1,9]. Condylar remodelling is regarded as a physiological process involving the equilibrium between bone resorption and bone formation due to changed condylar loads and positioning. It is currently hypothesized that symptoms do not occur in this group, unless excessive forces are applied during the postoperative remodelling period[4,10,11]. When this process exceeds its physiological limits, bone resorption outweighs bone formation and condylar resorption occurs[9,10,12]. This is characterized by progressive morphological changes with a decrease in condylar mass and volume, leading to a decreased condyle and ramus height. Clinical symptoms that are reported include the development or relapse of a class II occlusal and skeletal relationship, emergence of an anterior open bite with clockwise rotation of the mandible, and a decrease in posterior facial height[1,3,9,10,13,14]. Other terms used in the literature for this process are condylysis, condylar atrophy, avascular necrosis, dysfunctional remodelling, and osteoarthrosis[9].

Few studies have reported on condylar changes, either remodelling or resorption, after orthognathic surgery in patients with class III dentofacial deformity. Since most of the research on condylar remodelling or condylar resorption has involved class II patients who have undergone mandibular advancement surgery or bimaxillary surgery, the incidence, definitions, and treatment protocols for condylar remodelling and condylar resorption are mostly based on this population[4]. Hence, there is a lack of evidence for the identification of risk factors and the diagnosis and treatment of condylar remodelling and condylar resorption in class III orthognathic patients. The aim of this systematic review was to assess the available scientific literature regarding the incidence and extent of condylar changes following orthognathic surgery in patients with class III dentofacial deformity.

## Methods

### Protocol

A systematic review of the literature was performed using the guidelines of the PRISMA Statement (Preferred Reporting Items for Systematic Reviews and Meta-Analyses)[15]. This study was not registered.

### Information sources

A literature search was conducted in August 2017 using the electronic databases PubMed (National Library of Medicine, NCBI), Cochrane Central Register of Controlled Trials, and Embase, to identify condylar changes in Angle class III patients after orthognathic surgery. The search included studies published between 1974 and June 2017.

### Search strategy

The following key words were used to build the search strategy: (''orthognathic surgery'') AND (''condylar resorption'' OR ''condylar atrophy'' OR condylolysis OR osteoarthritis OR ''condylar remodelling'' OR ''condylar cartilage'' OR ''mandibular condyle'') AND (''Angle class III malocclusion''). The search strategy consisted of the use of free text terms in PubMed; Cochrane Central Register of Controlled Trials; and Embase; as well as medical subject heading (MeSH) terms in PubMed. A hand search of the reference lists of the identified articles was performed to reveal additional relevant articles not retrieved in the database search.

### Selection of studies

The selection of articles was conducted by two independent reviewers (ASV and PJV). After removing duplicates, one reviewer first screened the titles and abstracts of all identified studies to extract the papers that were definitely not relevant to the subject of this literature review. In the case of uncertainty, the article was included anyway. The full text of the selected publications that needed further consideration was obtained and read by both reviewers, and checked against predetermined eligibility criteria. Whenever there was disagreement, a discussion and consensus procedure followed.

### Eligibility criteria

Articles meeting the following criteria were included: (1) randomized clinical trial, non-randomized clinical trial, prospective study, retrospective study, or case series study design; (2) full text available in the English language; (3) participants were patients who underwent orthognathic surgery for a class III dentofacial deformity; (4) the intervention was any type of osteotomy to correct the class III dentofacial deformity; (5) all follow-up observation periods were accepted; (6) outcomes assessed were radiological or clinical signs of condylar remodelling or condylar resorption.

The following exclusion criteria were established: (1) animal studies; (2) literature reviews; (3) congress abstracts; (4) no full text available in international databases; (5) cases of syndromic or systemic disease related to condylar resorption; (6) patients who underwent distraction osteogenesis.

### Data collection process

Data from each study were independently extracted and evaluated by the two reviewers. The data recorded were first author, publication year, study design, details of the intervention, patient characteristics, observation period, methods of outcome assessment, and all reported radiological or clinical signs of condylar remodelling or condylar resorption.

### Risk of bias assessment

A methodological quality and bias assessment was performed independently by two reviewers (ASV, PJV). Any inter-examiner conflicts were resolved by discussion. Randomized controlled trials were evaluated using the Cochrane risk of bias tool[16], whereas non-randomized retrospective and prospective studies were evaluated using the methodological index for non-randomized studies (MINORS)[17]. This index scores prospective and retrospective studies in eight domains for non-comparative studies and 12 domains for comparative studies. The ideal score is 16 for non-comparative studies and 24 for comparative studies, and these are correlated with high quality and a low risk of bias.

## Results

### Study selection

The search yielded a total of 564 results. After the removal of duplicates, 442 unique citations were obtained. Twenty-eight more publications were found by manual search of the reference lists of the identified articles. These 470 records were screened by title and abstract. This selection procedure resulted in 121 potentially relevant articles. Further evaluation of the full text eliminated 109 more articles: six were excluded because they were not available in the English language, another five articles had no full text available in international libraries, and 98 articles were not relevant to the subject of the systematic review. Finally, 12 articles meeting the inclusion criteria were obtained for data extraction and analysis (Fig. 1).

#### Study characteristics

Every article included provided an insight into radiological or clinical signs of condylar resorption or condylar remodelling after orthognathic surgery in patients with a class III deformity. Table 1 presents an overview of the characteristics of each study. With regard to the study design, all articles reported non-randomized retrospective studies.

Details of the outcomes studied, methods of outcome assessment, and follow-up are given in Table 2. The follow-up period varied between 10 months and 16 years. The total number of patients included in all of the studies was 1376. Of these patients, 477 had a class III dentofacial deformity with a range of 12–210 class III patients across the studies. The age of the patients ranged from 17 to 43 years. Since no randomized studies were included, the assessment of bias was performed using MINORS[17]. Only one comparative study was identified; this yielded a score of 14 out of 24, indicating a moderate risk of bias[7]. The other 11 non-comparative studies had a mean score of 10.3 out of 16, also indicating a moderate risk of bias. The most frequently seen methodological flaws were an incomplete description of the protocol used for patient selection, absence of a prospective sample size calculation, and the lack of an unbiased assessment of the outcome variables. There was no need to exclude specific studies based on the risk of bias assessment, as there were no important methodological errors that would have had a relevant effect on the analysis.

Only a few recent studies investigated the condylar morphology and surface changes after orthognathic surgery using cone beam computed tomography (CBCT)[18–20]. One study, reported in 2006, used spiral computed tomography (CT) for the assessment of condylar head remodelling[21]. Cephalometric and panoramic radiographs with or without clinical examination were the methods used to assess the outcomes in the other studies. Mandibular setback was performed alone[7,18,19,21–26], or in combination with other surgical procedures[18,20,27,28].

#### Condylar remodelling following orthognathic surgery

Table 3 presents the results, conclusions, and noted condylar changes found in the selected studies. Table 4 provides a visual overview of the results found in these class III patients. Eight studies reported a certain degree of condylar remodelling[18–24,28]. Two of the retrieved studies investigated but found no association between mandibular setback and alterations of the condyle[7,27]. Only patients who underwent an advancement procedure were susceptible to condylar morphology changes in these studies[7,27].

In the CBCT-based studies, condylar remodelling was classified into three categories: bone resorption, unchanged surface, and bone formation[18–20]. The study by An et al. described the changes in six areas on the condylar head[18]. Among the signs of condylar remodelling, resorption (41.7%) was observed the most. Bone formation occurred in 37.5% of the condyles. Remodelling did not occur more often in specific

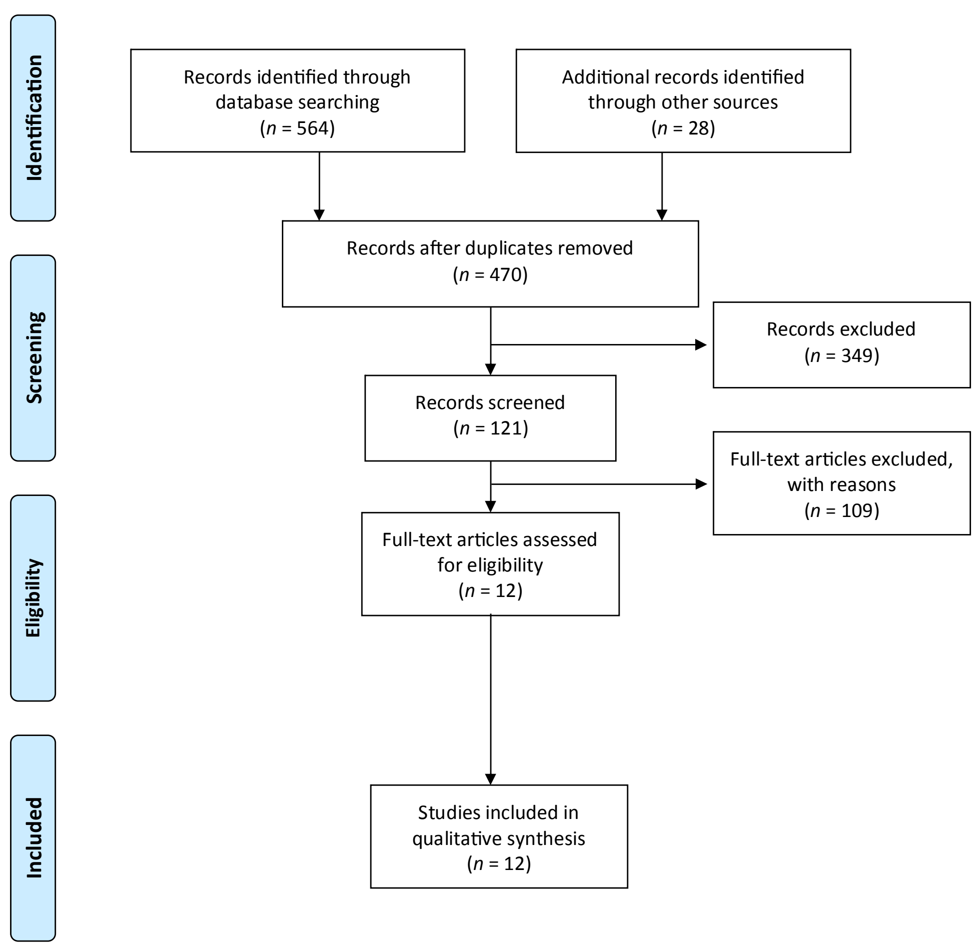



*Fig. 1.* Flowchart of the study selection process.

*Table 1*. Overview of study characteristics.

| Author (Year) | Title | Study design | Country | Assessment of bias (MINORS[a]) | Number of class III patients | Type of surgery[b] | Class I or II patients studied |
|---|---|---|---|---|---|---|---|
| An et al.[18] (2014) | Effect of post-orthognathic surgery condylar axis changes on condylar morphology as determined by 3-dimensional surface reconstruction. | RS | South Korea | 11/16 | 30 | BSSO setback (15) Bimaxillary surgery (15) | No |
| Aneja et al.[22] (2017) | Evaluation of mandibular condylar changes in patients following orthognathic surgery: a retrospective study. | RS | India | 8/16 | 10 | BSSO setback | Yes |
| Ha et al.[19] (2013) | Cone-beam computed tomographic evaluation of the condylar remodeling occurring after mandibular set-back by bilateral sagittal split ramus osteotomy and rigid fixation. | RS | South Korea | 10/16 | 22 | BSSO setback | No |
| Park et al.[20] (2012) | Effect of bimaxillary surgery on adaptive condylar head remodeling: metric analysis and image interpretation using cone-beam computed tomography volume superimposition. | RS | South Korea | 11/16 | 22 | Bimaxillary surgery | No |
| Katsumata et al.[21] (2006) | Condylar head remodeling following mandibular setback osteotomy for prognathism: a comparative study of different imaging modalities. | RS | Japan and USA | 9/16 | 85 | BSSO setback (39) IVRO (46) | No |
| Wolford et al.[27] (2002) | Concomitant temporomandibular joint and orthognathic surgery: a preliminary report. | RS | USA | 12/16 | 7 | BSSO setback and TMJ disc repositioning | Yes |
| Bouwman et al.[7] (1994) | Condylar resorption in orthognathic surgery. The role of intermaxillary fixation. | RS | Netherlands | 14/24 | 210 | IVRO | Yes |
| Wohlwender et al.[28] (2011) | Condylar resorption and functional outcome after unilateral sagittal split osteotomy. | RS | Germany | 8/16 | 20 | USSO setback | Yes |
| Eggensperger et al.[23] (2005) | Mandibular setback by sagittal split ramus osteotomy: a 12-year follow-up. | RS | Switzerland | 10/16 | 12 | BSSO setback | No |
| Huang et al.[24] (2006) | Mandibular remodeling after bilateral sagittal split osteotomy for prognathism of the mandible. | RS | Taiwan | 10/16 | 20 | BSSO setback | No |
| Joss and Thuer[25] (2008) | Stability of hard tissue profile after mandibular setback in sagittal split osteotomies: a longitudinal and long-term follow-up study. | RS | Switzerland | 14/16 | 17 | BSSO setback | No |
| Morrill et al.[26] (1974) | Surgical correction of mandibular prognathism. I. A cephalometric report. | RS | USA | 10/16 | 22 | IVRO | No |

BSSO, bilateral sagittal split osteotomy; IVRO, intraoral vertical ramus osteotomy; RS, retrospective study; TMJ, temporomandibular joint; USSO, unilateral sagittal split osteotomy.

[a] Methodological index for non-randomized studies (MINORS): ideal scores are 16 for non-comparative studies and 24 for comparative studies.

[b] Surgery performed in class III patients.

*Table 2.* Overview of the follow-up period, outcomes studied, and methods of outcome assessment[a].

| Author (Year) | Follow-up period (months) | Outcomes studied | | | | Methods of outcome assessment | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Condylar morphology | Condylar axis | Ramus height | Skeletal stability | Panoramic radiograph | Cephalometric radiograph | CBCT | Other |
| An et al.[18] (2014) | 10–19 | + | + | – | – | – | – | + | – |
| Aneja et al.[22] (2017) | 24 | + | – | + | + | + | + | – | – |
| Ha et al.[19] (2013) | 15.8 | + | + | – | – | – | – | + | – |
| Park et al.[20] (2012) | 16 (± 4.10) | + | + | – | – | – | – | + | – |
| Katsumata et al.[21] (2006) | 24 | + | + | – | – | – | + | – | CT and MRI |
| Wolford et al.[27] (2002) | 12–101 | + | – | + | – | + | + | – | Tomography |
| Bouwman et al.[7] (1994) | 12 | + | – | – | – | + | + | – | – |
| Wohlwender et al.[28] (2011) | 12–65 | + | – | + | + | + | + | – | – |
| Eggensperger et al.[23] (2005) | 132–192 | – | – | + | + | – | + | – | – |
| Huang et al.[24] (2006) | 24–53 | + | – | – | + | – | + | – | – |
| Joss and Thuer[25] (2008) | 132–168 | – | – | – | + | – | + | – | – |
| Morrill et al.[26] (1974) | 12 | – | – | – | + | – | + | – | – |

CBCT, cone beam computed tomography; CT, computed tomography; MRI, magnetic resonance imaging.
[a] '+': type of outcome was studied, or method of outcome assessment was used; '–': type of outcome was not studied, or method of outcome assessment was not used.

areas. Ha et al.[19] and Park et al.[20] divided the condylar head into 12 areas and stated that some areas were more prone to remodelling than others. The study by Ha et al. reported that most of the resorption was seen in the anterosuperior areas in the sagittal plane, in the laterosuperior areas in the coronal plane, and in the anterocentral and anterolateral areas in the axial plane[19]. In contrast, Park et al. observed a predominance of resorption in the anterolateral and posterolateral areas in the axial plane[20]. As well as the resorption, Park et al. also described an area with bone formation. The results for the coronal and sagittal planes were similar. Furthermore, both studies found a decrease in condylar height in the coronal and sagittal planes following surgery. However, the condylar changes seen in these studies did not result in any clinical signs or symptoms of a temporomandibular disorder.

Aneja et al. measured the distance from articulare to gonion[22]. The shortening was calculated in relation to the total length of the ramus and was indicative of condylar changes. Only a setback of more than 6 mm showed significant condylar alterations. The nature of the changes was not further specified. Some studies used the intraoral vertical ramus osteotomy (IVRO) method to achieve setback[7,21,26]. Katsumata et al. did a post-hoc comparison between IVRO and sagittal ramus osteotomy (SSO) and found that in the IVRO group, 47 out of 92 studied condyles showed signs of remodelling (51.1%)[21]. The SSO group had a lower rate of condylar remodelling, namely eight out of 78 studied condyles (10.3%).

#### Skeletal relapse

Skeletal relapse following orthognathic correction of class III patients was defined as a postoperative anterior movement of the mandible[23-26]. Eggensperger et al.[23] and Joss and Thuer[25] both had an average follow-up period of 12 years. They found a skeletal relapse measured at B-point of 14% and 15%, respectively, relative to the amount of setback. The study of Eggensperger et al. did not observe further relapse after the first year but did observe a progressive decrease in ramus height[23]. A remarkable finding from Joss and Thuer was the occurrence of further distalization of the mandible after bilateral sagittal split osteotomy (BSSO) setback[25]. There was a clear female predominance. A similar finding was seen in the study of Morrill et al.[26]. Five out of 22 of patients presented with a pogonion that had moved further posterior during the postoperative period. In addition, there was a tendency to open bite.

#### Condylar axis changes

Four of the included studies investigated the effect of condylar axis changes on the prevalence of remodelling[18–21]. An et al.[18], Ha et al.[19] and Park et al.[20] found an inward rotation of the condylar axis in the axial plane after BSSO, and the correlation with remodelling was significant in all of them. In contrast, Katsumata et al. reported no rotation of the condylar axis after BSSO[21]. However, the IVRO group in that study showed an outward rotation of the condyle in 79 out of 92 studied condyles (85.9%), which they associated with a higher rate of condylar remodelling.

#### Setback surgery for laterognathia

Lastly, one study investigated condylar resorption after orthognathic surgery to correct laterognathia[28]. Two out of 20 patients who received a unilateral sagittal split osteotomy (USSO) setback showed signs of condylar resorption and an in-

*Table 3*. Overview of the study results[a].

| Author Year | Condylar axis changes | Condylar remodelling | Condylar resorption | Condylar height loss | Ramus height loss | Skeletal instability | | Conclusions |
|---|---|---|---|---|---|---|---|---|
| | | | | | | Relapse | Distalization | |
| An et al.[18] (2014) | + | + | ND | ND | ND | ND | ND | Inward axis rotation was correlated with condylar remodelling. Bone resorption was more frequent than bone formation. |
| Aneja et al.[22] (2017) | ND | + | ND | ND | + | ND | ND | Condylar remodelling is more prevalent after mandibular advancement than setback surgery. It does occur after setback surgery, especially if a setback of more than 6 mm is performed. |
| Ha et al.[19] (2013) | + | + | ND | + | – | ND | ND | BSSO setback resulted in inward rotation, a condylar height decrease, and overall condylar remodelling of the condylar head. Bone resorption occurred mostly on the anterosuperior surface of the condyle. These changes did not cause clinical signs. |
| Park et al.[20] (2012) | + | + | ND | + | ND | ND | ND | Significant inward rotation of the condylar axis was noted. CBCT showed condylar remodelling with a decrease in condylar height after bimaxillary surgery. These changes did not cause clinical signs. |
| Katsumata et al.[21] (2006) | + | + | ND | – | ND | ND | ND | Condylar remodelling was more frequent in the IVRO group than in the SSRO group. There was a positive correlation between condylar axis rotation and the incidence of remodelling. |
| Wolford et al.[27] (2002) | ND | – | – | ND | ND | + | – | No class III patients showed signs of excessive condylar remodelling or condylar resorption after bimaxillary surgery. Skeletal instability with relapse measured at B-point was noted. |
| Bouwman et al.[7] (1994) | ND | – | – | ND | ND | ND | ND | No class III patients showed signs of excessive condylar remodelling or condylar resorption after IVRO for mandibular prognathism |
| Wohlwender et al.[28] (2011) | ND | + | + | ND | + | – | + | Condylar resorption was noted in 2 patients who had a USSO. Skeletal instability with a decrease in SNB angle occurred. |
| Eggensperger et al.[23] (2005) | ND | + | ND | ND | + | + | – | Skeletal instability occurred after BSSO setback. A decrease in ramus length was described. Condylar morphological changes are suggested. |
| Huang et al.[24] (2006) | ND | + | ND | + | ND | – | – | Condylar remodelling was noted after setback procedures. The condylar height shortened. This had no effect on skeletal stability. |
| Joss and Thuer[25] (2008) | ND | ND | ND | ND | ND | + | + | Condylar remodelling was not explicitly mentioned. Some patients presented a further distalization of the mandible. Skeletal instability was noted. |
| Morrill et al.[26] (1974) | ND | ND | ND | ND | ND | + | + | Some patients showed further distalization of the mandible and developed an open bite tendency. |

BSSO, bilateral sagittal split osteotomy; CBCT, cone beam computed tomography; IVRO, intraoral vertical ramus osteotomy; ND, not described in the study; SNB, sella–nasion–B-point angle; SSRO, sagittal split ramus osteotomy; USSO, unilateral sagittal split osteotomy.

[a] '–': outcome was studied but not found in the study; '+': outcome was studied and found in the study.

*Table 4*. Visual overview of study results in class III patients.

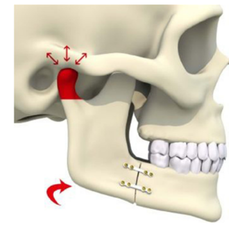
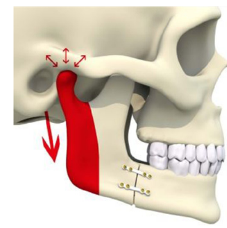
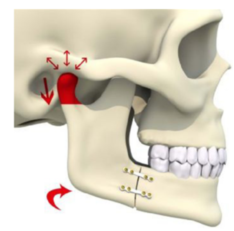
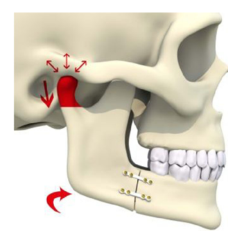
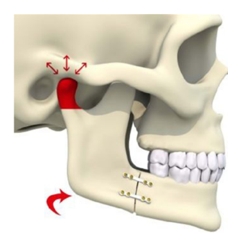
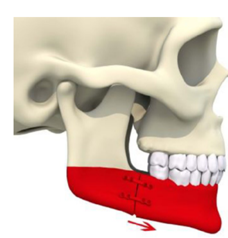
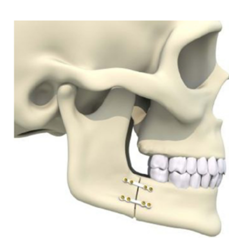
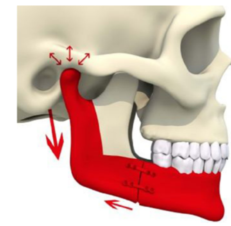
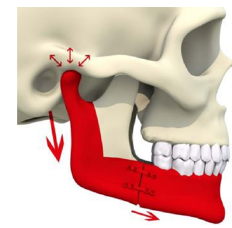
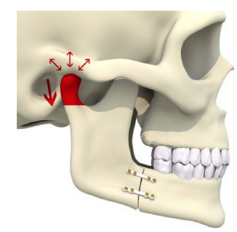
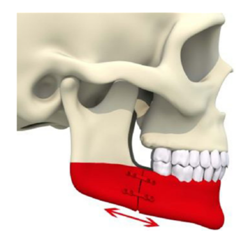
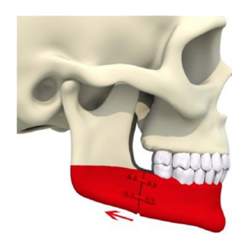
| Author (year) | Title | |
|---|---|---|
| An et al.[18] (2014) | Effect of post-orthognathic surgery condylar axis changes on condylar morphology as determined by 3-dimensional surface reconstruction. |  |
| Aneja et al.[22] (2017) | Evaluation of mandibular condylar changes in patients following orthognathic surgery: a retrospective study. |  |
| Ha et al.[19] (2013) | Cone-beam computed tomographic evaluation of the condylar remodeling occurring after mandibular set-back by bilateral sagittal split ramus osteotomy and rigid fixation. |  |
| Park et al.[20] (2012) | Effect of bimaxillary surgery on adaptive condylar head remodeling: metric analysis and image interpretation using cone-beam computed tomography volume superimposition. |  |
| Katsumata et al.[21] (2006) | Condylar head remodeling following mandibular setback osteotomy for prognathism: a comparative study of different imaging modalities. |  |
| Wolford et al.[27] (2002) | Concomitant temporomandibular joint and orthognathic surgery: a preliminary report. |  |
| Bouwman et al.[7] (1994) | Condylar resorption in orthognathic surgery. The role of intermaxillary fixation. |  |

Table 4 (*Continued*)

| Author (year) | Title | |
|---|---|---|
| Wohlwender et al.[28] (2011) | Condylar resorption and functional outcome after unilateral sagittal split osteotomy. |  |
| Eggensperger et al.[23] (2005) | Mandibular setback by sagittal split ramus osteotomy: a 12-year follow-up. |  |
| Huang et al.[24] (2006) | Mandibular remodeling after bilateral sagittal split osteotomy for prognathism of the mandible. |  |
| Joss and Thuer[25] (2008) | Stability of hard tissue profile after mandibular setback in sagittal split osteotomies: a longitudinal and long-term follow-up study. |  |
| Morrill et al.[26] (1974) | Surgical correction of mandibular prognathism. I. A cephalometric report. |  |

crease in the sella–nasion–B-point (SNB) angle. One also experienced a loss of ramus height.

## Discussion

This systematic review of the available literature was conducted to identify evidence of condylar remodelling and condylar resorption after orthognathic surgery in patients with a class III dentofacial deformity. All 12 of the studies included reported on postoperative condylar changes and their consequences. Eight of the 12 studies reported some degree of postoperative condylar remodelling[18–24,28]. A loss of ramus height was found in three studies[22,23,28] and a decreased condylar height was also noted in three studies[19,20,24]. Progressive posterior displacement of the mandible after setback surgery was described in three studies[25,26,28]. These findings suggest that condylar changes do occur following orthognathic surgery in patients with class III deformity. Despite not being explicitly labelled as condylar resorption, some cases were described in which a significant reduction in ramus and condylar height or a progressive posterior displacement after setback surgery was noted. This type of skeletal instability is expected when condylar resorption occurs.

Two studies compared the incidence of condylar resorption between class II and class III patients[7,27]. They both concluded that only the patients with mandibular hypoplasia showed signs of resorption. Factors that may contribute to the higher susceptibility of class II patients are the trabecular pattern of the condyles and the preoperative condylar volume. Krisjane et al. described a tendency for smaller condyle measurements in Angle class II patients with a high mandibular plane angle[29]. Smaller condyles are associated with a decreased adaptive capacity and are therefore prone to condylar resorption. O'Ryan and Epker reported that class II patients with a high mandibular plane angle had condyles with a less dense trabecular pattern[30].

Other risk factors for the development of condylar resorption are a high mandibular plane angle, an anterior open bite, a low posterior-to-anterior facial height[9,27], and a posteriorly inclined condylar neck[31]. These are all derived from research on class II patients. Surgical risk factors include counterclockwise rotation of the mandible and large surgical movements[32]. The latter was confirmed in one of the included studies, where more condylar remodelling was noted if setback exceeded 6 mm[22]. Another possible causal factor is the inward rotation of the condylar axis after setback surgery. An et al.[18], Ha et al.[19], and Park et al.[20] found a significant correlation with remodelling.

Eggensperger et al. stated that one of the main mechanisms contributing to long-term skeletal relapse is condylar resorption and condylar remodelling[23]. However, only two of the 12 included studies had a follow-up period longer than 10 years[23,25]. As many studies had a follow-up ranging from 6 months to 2 years, long-term data are difficult to find and conclusions regarding long-term skeletal relapse and its relationship with condylar remodelling and condylar resorption should be drawn with caution. Future research providing long-term follow-up should be encouraged and could provide answers regarding this topic.

This systematic review also revealed that research on this topic is incoherent and no longer up to date. Although most studies had a similar main goal (e.g., identifying condylar changes after orthognathic surgery for class III patients), the intervention, outcome, and methods of outcome assessment used, and therefore the results obtained, varied. Furthermore, most studies were performed without the availability of CBCT image acquisition and its potential for enhanced image analysis. The conventional two-dimensional imaging techniques that were used lack accuracy and reproducibility and can be considered inferior to CBCT image analysis for the assessment of condylar morphological changes. Only four studies that evaluated the postoperative condylar changes with CBCT or CT were identified[18–21]. CBCT image acquisition provides useful data in the planning and postoperative evaluation of orthognathic surgery. It allows three-dimensional (3D) visualization of the condyles using both 3D volume and surface rendering techniques and also the analysis of condylar volumes through the application of validated segmentation techniques[33]. By voxel-based superimposition of pre- and postoperative CBCT data, the amount and localization of condylar resorption can be identified.

The studies included that used CBCT showed that in condylar remodelling, bone resorption was more prevalent than bone formation. The most affected region of the condyle was the antero-superolateral area. The studies of Ha et al.[19] and Park et al.[20] showed a significant decrease in condylar height; however, no associated dentofacial changes or symptoms were mentioned. Neither of these studies calculated condylar volumes; instead they used measurements in the sagittal, axial, and coronal planes to study condylar morphology.

The availability of CBCT image acquisition with consecutive 3D image analysis by both surface and volume rendering and condylar 3D volume calculation become even more interesting if they are combined with 3D cephalometric analysis. 3D cephalometric analysis is now used in 3D orthognathic planning protocols[34,35]. By combining condylar changes and 3D cephalometric data and comparing pre- and postoperative data, the effect of condylar changes on skeletal stability post-orthognathic surgery can be objectified. Xi et al. used this technique to report on condylar volume changes and their relationship to skeletal relapse in patients with a class II dentofacial deformity who were treated by BSSO advancement[8]. A cut-off value of a 17% reduction in condylar volume was proposed to identify the process as condylar resorption, leading to skeletal relapse. It should however be noted that this cut-off value is based on a limited study population that only included class II patients.

Most reports on condylar remodelling and condylar resorption have been based on class II patients and used panoramic and cephalometric radiographs combined with clinical examinations to acquire data. The present systematic review identified the occurrence of condylar remodelling following mandibular setback procedures for class III patients. Also, signs of condylar resorption were described in this population, e.g. loss of condyle and ramus height and progressive posterior displacement of the mandible after setback surgery. Only a few studies with a relatively small sample size have been conducted on this subject, and the amount of heterogeneity between the studies is high. So although there are anecdotal reports that condylar resorption also occurs in class III patients, it is difficult to draw conclusions based on the current literature. Furthermore, the definition of condylar resorption includes 'clinical relapse', which would be an impossible combination with condylar resorption in class III patients. The opposite would occur in class III patients suffering postoperative condylar resorption: the setback would be aggravated due to the loss of height of the condyle.

Further evidence-based research is needed to identify and quantify condylar remodelling and its effect on skeletal stability after orthognathic surgery for both class III and class II patients. CBCT image acquisition and 3D analysis, 3D condylar volume calculation, and 3D cephalometry provide great opportunities to aid in this endeavour.

## Funding

None.

## Competing interests

None.

## Ethical approval

Not applicable.

## Patient consent

Not applicable.

## References

1. Hoppenreijs TJ, Freihofer HP, Stoelinga PJ, Tuinzing DB, van't Hof MA. Condylar remodelling and resorption after Le Fort I and bimaxillary osteotomies in patients with anterior open bite. *Int J Oral Maxillofac Surg* 1998;**27**:81–91. http://dx.doi.org/10.1016/S0901-5027(98)80301-9.
2. Borstlap WA, Stoelinga PJ, Hoppenreijs TJ, van't Hof MA. Stabilisation of sagittal split advancement osteotomies with miniplates: a prospective, multicentre study with two-year follow-up. *Int J Oral Maxillofac Surg* 2004;**33**:649–55. http://dx.doi.org/10.1016/j.ijom.2004.01.018.
3. de Moraes PH, Rizzati-Barbosa CM, Olate S, Moreira RW, de Moraes M. Condylar resorption after orthognathic surgery: a systematic review. *Int J Morphol* 2012;**30**:1023–8. http://dx.doi.org/10.4067/S0717-95022012000300042.
4. Catherine Z, Breton P, Bouletreau P. Condylar resorption after orthognathic surgery: a systematic review. *Rev Stomatol Chir Maxillofac Chir Orale* 2016;**117**:3–10. http://dx.doi.org/10.1016/j.revsto.2015.11.002.

5. Mousoulea S, Kloukos D, Sampaziotis D, Vogiatzi T, Eliades T. Condylar resorption in orthognathic patients after mandibular bilateral sagittal split osteotomy: a systematic review. *Eur J Orthod* 2017;**39**:294–309. http://dx.doi.org/10.1093/ejo/cjw045.
6. Van Damme PA, Merkx MA. Condylar resorption after orthognathic surgery. *J Oral Maxillofac Surg* 1994;**52**:1347–8.
7. Bouwman JP, Kerstens HC, Tuinzing DB. Condylar resorption in orthognathic surgery. The role of intermaxillary fixation. *Oral Surg Oral Med Oral Pathol* 1994;**78**:138–41. http://dx.doi.org/10.1016/0030-4220(94)90135-X.
8. Xi T, Schreurs R, van Loon B, de Koning M, Bergé S, Hoppenreijs T, Maal T. 3D analysis of condylar remodelling and skeletal relapse following bilateral sagittal split advancement osteotomies. *J Craniomaxillofac Surg* 2015;**43**:462–8. http://dx.doi.org/10.1016/j.jcms.2015.02.006.
9. Arnett GW, Milam SB, Gottesman L. Progressive mandibular retrusion—idiopathic condylar resorption. *Part I Am J Orthod Dentofacial Orthop* 1996;**110**:8–15.
10. Arnett GW, Gunson MJ. Risk factors in the initiation of condylar resorption. *Semin Orthod* 2013;**19**:81–8. http://dx.doi.org/10.1053/j.sodo.2012.11.001.
11. Handelman CS, Greene CS. Progressive/idiopathic condylar resorption: an orthodontic perspective. *Semin Orthod* 2013;**19**:55–70. http://dx.doi.org/10.1053/j.sodo.2012.11.004.
12. Hoppenreijs TJ, Maal T, Xi T. Evaluation of condylar resorption before and after orthognathic surgery. *Semin Orthod* 2013;**19**:106–15. http://dx.doi.org/10.1053/j.sodo.2012.11.006.
13. Sansare K, Raghav M, Mallya SM, Karjodkar F. Management-related outcomes and radiographic findings of idiopathic condylar resorption: a systematic review. *Int J Oral Maxillofac Surg* 2015;**44**:209–16. http://dx.doi.org/10.1016/j.ijom.2014.09.005.
14. Huang YL, Pogrel MA, Kaban LB. Diagnosis and management of condylar resorption. *J Oral Maxillofac Surg* 1997;**55**:114–9. discussion 119–120.
15. Moher D, Liberati A, Tetzlaff J, Altman DG. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. *PLoS Med* 2009;**6**:e1000097. http://dx.doi.org/10.1371/journal.pmed.1000097.
16. Higgins J, Green S. *Cochrane handbook for systematic reviews of interventions version 5.1.0*. The Cochrane Collaboration; 2011.
17. Slim K, Nini E, Forestier D, Kwiatkowski F, Panis Y, Chipponi J. Methodological index for non-randomized studies (MINORS): development and validation of a new instrument. *ANZ J Surg* 2003;**73**:712–6. http://dx.doi.org/10.1046/j.1445-2197.2003.02748.x.
18. An SB, Park SB, Kim YI, Son WS. Effect of post-orthognathic surgery condylar axis changes on condylar morphology as determined by 3-dimensional surface reconstruction. *Angle Orthod* 2014;**84**:316–21. http://dx.doi.org/10.2319/052113-387.1.
19. Ha MH, Kim YI, Park SB, Kim SS, Son WS. Cone-beam computed tomographic evaluation of the condylar remodeling occurring after mandibular set-back by bilateral sagittal split ramus osteotomy and rigid fixation. *Korean J Orthod* 2013;**43**:263. http://dx.doi.org/10.4041/kjod.2013.43.6.263.
20. Park SB, Yang YM, Kim YI, Cho BH, Jung YH, Hwang DS. Effect of bimaxillary surgery on adaptive condylar head remodeling: metric analysis and image interpretation using cone-beam computed tomography volume superimposition. *J Oral Maxillofac Surg* 2012;**70**:1951–9. http://dx.doi.org/10.1016/j.joms.2011.08.017.
21. Katsumata A, Nojiri M, Fujishita M, Ariji Y, Ariji E, Langlais RP. Condylar head remodeling following mandibular setback osteotomy for prognathism: a comparative study of different imaging modalities. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 2006;**101**:505–14. http://dx.doi.org/10.1016/j.tripleo.2005.07.028.
22. Aneja V, Raval R, Aneja P, Rai K, Agarwal S, Chuadhary S. Evaluation of mandibular condylar changes in patients following orthognathic surgery: a retrospective study. *Niger J Surg* 2017;**23**:37. http://dx.doi.org/10.4103/1117-6806.199961.
23. 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.
24. Huang CS, de Villa GH, Liou EJ, Chen YR. Mandibular remodeling after bilateral sagittal split osteotomy for prognathism of the mandible. *J Oral Maxillofac Surg* 2006;**64**:167–72. http://dx.doi.org/10.1016/j.joms.2005.10.008.
25. 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.
26. Morrill LR, Baumrind S, Miller D. Surgical correction of mandibular prognathism. I. A cephalometric report. *Am J Orthod* 1974;**65**:503–18.
27. Wolford LM, Karras S, Mehra P. Concomitant temporomandibular joint and orthognathic surgery: a preliminary report. *J Oral Maxillofac Surg* 2002;**60**:356–62. http://dx.doi.org/10.1053/joms.2002.31220.
28. Wohlwender I, Daake G, Weingart D, Brandstätter A, Kessler P, Lethaus B. Condylar resorption and functional outcome after unilateral sagittal split osteotomy. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 2011;**112**:315–21. http://dx.doi.org/10.1016/j.tripleo.2010.10.030.
29. Krisjane Z, Urtane I, Krumina G, Zepa K. Three-dimensional evaluation of TMJ parameters in class II and class III patients. *Stomatologija* 2009;**11**:32–6.
30. O'Ryan F, Epker BN. Temporomandibular joint function and morphology: observations on the spectra of normalcy. *Oral Surg Oral Med Oral Pathol* 1984;**58**:272–9. http://dx.doi.org/10.1016/0030-4220(84)90052-5.
31. Hwang SJ, Haers PE, Sailer HF. The role of a posteriorly inclined condylar neck in condylar resorption after orthognathic surgery. *J Craniomaxillofac Surg* 2000;**28**:85–90. http://dx.doi.org/10.1054/jcms.2000.0129.
32. Hwang SJ, Haers PE, Zimmermann A, Oechslin C, Seifert B, Sailer HF. Surgical risk factors for condylar resorption after orthognathic surgery. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 2000;**89**:542–52.
33. Xi T, Schreurs R, Heerink WJ, Bergé SJ, Maal TJ. A novel region-growing based semi-automatic segmentation protocol for three-dimensional condylar reconstruction using cone beam computed tomography (CBCT). *PLoS One* 2014;**9**:e111126. http://dx.doi.org/10.1371/journal.pone.0111126.
34. Swennen GR, Schutyser F. Three-dimensional cephalometry: spiral multi-slice vs cone-beam computed tomography. *Am J Orthod Dentofacial Orthop* 2006;**130**:410–6. http://dx.doi.org/10.1016/j.ajodo.2005.11.035.
35. Swennen GR, Schutyser F, Barth E, De Groeve P, De Mey A. A new method of 3-D cephalometry part I: the anatomic Cartesian 3-D reference system. *J Craniofac Surg* 2006;**17**:314–25. http://dx.doi.org/10.1097/00001665-200603000-00019.

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