Systematic review

Association between posterior crossbite, skeletal, and muscle asymmetry: a systematic review

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Summary

Background: Of the various malocclusions, unilateral posterior crossbite has often been associated to skeletal and muscular asymmetrical growth and function.

Objective: To assess, by systematically reviewing the literature, the association between unilateral posterior crossbite (UPCB) and morphological and/or functional asymmetries (i.e. skeletal, masticatory muscle electromyographic (EMG) performance, bite force, muscle thickness, and chewing cycle asymmetries).

Materials and Methods: A literature survey covering the period from January 1965 to June 2015 was performed. Two reviewers extracted the data independently and assessed the quality of the studies.

Results: The search strategy resulted in 2184 citations, of which 45 met the inclusion criteria. The scientific and methodological quality of these studies was medium–low, irrespective of the association reported. In several studies, posterior crossbite is reported to be associated to asymmetries in mandibular skeletal growth, EMG activity, and the chewing cycle. Fewer data are available on bite force and masticatory muscle thickness.

Conclusions: The relationship between unilateral posterior crossbite and skeletal asymmetry is still unresolved. To date, most of the studies available report a skeletal asymmetric growth. EMG activity of masticatory muscles is different between crossbite and non-crossbite sides. Subjects with UPCB show smaller bite force than non-crossbite subjects. There is no consistency of studies reporting masticatory muscle thickness asymmetry in UPCB subjects. UPCB is associated to an increase in the reverse chewing cycle. The literature available on the subject is of medium–low scientific and methodological quality, irrespective of the association reported. Further investigations with higher sample size, well-defined diagnostic criteria, rigorous scientific methodologies, and long-term control are needed.

Introduction

Posterior crossbite is defined as the presence of one or more teeth of the posterior group (from canine to second molar) in an irregular (at least one cusp wide) bucco-lingual or bucco-palatal relationship, with one or more opposing teeth in centric occlusion (1). Its prevalence in the primary and early mixed dentition is reported to occur in 8–22% of orthodontic patients (2–4) and in 5–15% of the general population (5–9). Dental, skeletal, and neuromuscular factors can be recognized as possible etiological factors.
factors, but the most frequent cause is reduction in width of the maxillary arch. Even if spontaneous correction can occur (10–13), posterior crossbite, and especially unilateral posterior crossbite, can result in mandibular shift and postural alterations, with a possible asymmetrical growth and function of the skeletal and muscle structures (14, 15).

It has been suggested that an altered morphological relationship between the upper and lower dentition is associated to right-to-left-side differences in the condyle–fossa relationship (16). The asymmetrical function in posterior crossbite patients was reported to be associated to different development of the right and left sides of the mandible over time (17–20), asymmetric contraction of the masticatory muscles (21–25), reduced thickness of the ipsilateral masseter muscle (26), and a different chewing pattern (27–29). However, others reported different findings (30–33) with a consequent inconsistency retrieved from the literature.

Therefore, the aim of our study was to perform a systematic review in order to investigate the association between posterior crossbite and morphological and/or functional asymmetries, i.e. skeletal, masticatory muscle electromyographic (EMG) performance, bite force, muscle thickness, and in chewing cycle asymmetries.

Materials and Methods
A literature survey was performed through the Medline database (Entrez PubMed, http://www.ncbi.nim.nih.gov) in order to investigate the correlations between posterior crossbite and different asymmetric conditions of the stomatognathic system. The research process analyzed studies published between 1 January 1966 and 27 June 2015, using the medical subject heading term: ‘crossbite’, which was crossed with the keywords ‘masticatory cycle’, ‘chewing cycle’, ‘asymmetry’, ‘bite force’, ‘EMG’, and ‘muscle thickness’.

Three researchers (GI, GD, and RC) selected the studies by reading the titles, and the abstracts, using specific inclusion and exclusion criteria. Inclusion criteria were human studies, posterior crossbite, lateral crossbite, retrospective studies with and without controls or reference group, and prospective studies. Instead, we excluded all articles not written in English, case reports and case series, reviews, studies with unclear diagnosis or poorly defined samples, treatment strategies and appliances, craniofacial syndrome diagnosis possibly influencing the prevalence of temporo mandibular disorders (TMD), those with full-text versions not available, and experimental animal studies. Therefore, the aim of our study was to perform a systematic review in order to investigate the association between posterior crossbite and morphological and/or functional asymmetries, i.e. skeletal, masticatory muscle electromyographic (EMG) performance, bite force, muscle thickness, and in chewing cycle asymmetries.

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Results
The flow chart of the search strategy is presented in Figure 1. The initial search yielded 2184 citations. After a selection according to the inclusion and exclusion criteria, 45 articles were analyzed.
Crossbite and Skeletal Asymmetry

Nineteen articles focused specifically on the relationship between crossbite and skeletal asymmetry. The quality was high (69%) in 9 studies, medium in 6 (31.6%), and low in 4 (20.8%). Table 1 and Supplementary Table 1 (available online).

Twelve studies (63.2%) reported a significant association between posterior crossbite and skeletal asymmetry (‘association’) with a mean score of 6.7: 11 (91.7%) with a medium score and 1 (8.3%) with a low score. Seven studies (36.8%) did not find any significant association between posterior crossbite and skeletal asymmetry (‘no association’) with a mean score of 6.2: five (71.4%) with a medium score and two (28.6%) with a low score. Mean years of publication for the articles were, respectively, 7.1 years for the ‘association’ and 9 years for the ‘no association’ articles. Neither quality assessment nor study years of publication differed between groups (P = 0.29 and P = 0.41, respectively). Fourteen studies included adolescents (8 reporting ‘association’; 6 reporting ‘no association’), and five studies adults (4 reporting ‘association’; 1 reporting ‘no association’).

Crossbite and EMG Activity

Eleven articles focused specifically on the relationship between crossbite and EMG activity. The quality was high in two studies (18.2%), medium in seven (63.6%), and low in two (18.2%). Table 2 and Supplementary Table 2 (available online).

All studies (100%) reported a significant association between posterior crossbite and EMG activity (‘association’) with a mean score of 6.4. Mean years of publication for the articles were 9.9 years. Eight studies included adolescents, and three studies adults.

Crossbite and Bite Force

Four articles focused specifically on the relationship between crossbite and bite force. The quality was assessed as high in one study (25%), medium in two (50%), and low in one (25%). Table 3 and Supplementary Table 3 (available online).

A significant association between posterior crossbite and bite force (‘association’) was reported in three studies (75%), with a mean score of 7.6. One study (25%) did not find any significant association between posterior crossbite and bite force (‘no association’) with a score of 4. Mean years of publication for the articles were, respectively, 9 years for the ‘association’ and 12 years for the ‘no association’ article. Quality assessment was significantly different (P = 0.07). No significant difference, instead, was found according to years of publication (P = 0.63). All studies included children/adolescents, ranging from 3.5 years (56-58) to 13 years old (55).

Crossbite and Masticatory Muscle Thickness

Four articles focused specifically on the relationship between crossbite and masticatory muscle thickness. All studies presented a medium quality score assessment (Table 4 and Supplementary Table 4, available online).

A significant association between posterior crossbite and masticatory muscle thickness (‘association’) was reported in two studies (50%), with a mean score of 7.5. Two studies (50%) did not find any significant association between posterior crossbite and masticatory muscle thickness (‘no association’), both reporting a medium score of 7. Mean years of publication for the articles were, respectively, 8 years for the ‘association’ and 5.5 years for the ‘no association’ articles. Quality assessment did not differ between groups (P = 0.42). By contrast, the years of studies publication differed between groups (P = 0.04). The studies included children/adolescents (2 reporting ‘association’; 2 reporting ‘no association’).

Crossbite and Chewing Cycle

Seven articles focused specifically on the relationship between crossbite and the chewing cycle. The quality was assessed as high in one study (14.3%) and medium in six (85.7%). Table 5 and Supplementary Table 5 (available online).

A significant association between posterior crossbite and chewing cycle (‘association’) was reported in five studies (71.4%), with a medium score (mean 7.4). Two studies (28.6%) did not find any significant association between posterior crossbite and chewing cycle (‘no association’) with a mean score of 7.5: one with a high score and one with a medium score. Mean years of publication for the articles were, respectively, 7 years for the ‘association’ and 10 years for the ‘no association’ articles. Neither quality assessment nor study years of publication differed between groups (P = 0.76 and P = 0.40, respectively). Three studies included children/adolescents (2 reporting ‘association’; 2 reporting ‘no association’), two studies adults (both reporting ‘association’), and one study included both adolescents and adults (reporting ‘association’).

Discussion

This systematic review aimed to select all prospective and retrospective observational studies with or without control groups, analyzing the association between posterior crossbite, skeletal, and muscle asymmetries. Forty-five studies were retrieved, some being included in more than one group of association. After scientific and methodological assessment, the quality of most studies was adjudged to be medium–low, deeply influencing the import and reliability of their relative results.

A previous systematic review of the association between unilateral posterior crossbite (UPCB) and functional changes (31) did not investigate skeletal asymmetries, muscle thickness, or the chewing cycle. The authors analyzed only two studies on EMG evaluation, whereas the present updated review included nine more recent studies. Another systematic review (62) analyzed the association between posterior unilateral crossbite and skeletal asymmetry. The authors included also treatment studies, did not consider muscular and functional fields, and did not include several studies reported in our review.

The problems found in all the studies analyzed in this review are the following. First, most of the samples were selected among orthodontic patients, dental students, or staff members, thus not representative of the general population with a consequent selection bias leading to unreliable results (63). Second, many studies included scantily described samples (15, 41, 48, 58), small sample size (14, 23, 41, 42, 44, 57), features poorly represented in the sample (i.e. only 3 of 45 patients presented crossbite in 51), and rarely reported predefined sample sizes (25). Third, the age of the sample differed greatly among studies including children or adults, with non-comparable results (64). Fourth, even though the harmful/detrimental effects of unilateral versus bilateral crossbite on specific muscle and/or skeletal asymmetries could be of particular interest, it was analyzed in very few studies. Finally, no study on the topic reported long-term data.

Crossbite and Skeletal Asymmetry

The existing relationship between posterior crossbite and skeletal asymmetries is still unresolved, with contrasting findings (20, 40, 43, 47). Indeed, a positive association between unilateral posterior crossbite and skeletal asymmetries was supported by 63% of the 19 analyzed studies. It has been hypothesized that the altered dental transversal
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<tbody>
<tr>
<td>Abad-Santamaria</td>
<td>2014</td>
<td>Cross-sectional with control group</td>
<td>UPCB 20 (14F, 6M)</td>
<td>60 sbj; 20 sbj UCLP; 20 sbj control group</td>
<td>Dental Clinic</td>
<td>UPCB: 9.1±2.2 ys; control group: 10.6±2 ys</td>
<td>Panoramic radiographs</td>
<td>Condylar asymmetry was observed in all three groups. No statistically significant differences were found among the three study groups for any of the asymmetry indexes.</td>
<td>No</td>
<td>6</td>
</tr>
<tr>
<td>Castelo</td>
<td>2010b</td>
<td>Cross-sectional with control group</td>
<td>DecC: 19 (9F, 10M); MixC: 16 (11F, 5M)</td>
<td>72 sbj DecN: 19 (4F, 15M); MixN: 27 (9F, 18M)</td>
<td>Dep. Pediatric dent.</td>
<td>DecC: 59.4±7 m; MixC: 73.2±7 m; DecN: 58.4±8 m; MixN: 65.7±10 m</td>
<td>Clinical examination and frontal photo</td>
<td>Children with functional posterior crossbite presented greater facial asymmetry than those with normal occlusion.</td>
<td>Yes</td>
<td>6</td>
</tr>
<tr>
<td>Cohlmia</td>
<td>1996</td>
<td>Observational study</td>
<td>Not reported</td>
<td>232 sbj (137F, 95M)</td>
<td>Preorthodontic subjects</td>
<td>9.4–42.6 ys Not reported for PCB patients 7–9.8 yrs range</td>
<td>Lateral Ceph RX</td>
<td>There was no significant difference in condylar position between individuals with/without crossbites.</td>
<td>No</td>
<td>5</td>
</tr>
<tr>
<td>Ferro</td>
<td>2011</td>
<td>Observational study</td>
<td>94 UPCB (60F, 34M)</td>
<td>94 sbj; (no control group)</td>
<td>Orthodontic patients</td>
<td>UPCB: 14.5±1.9 ys; PCB: 14.6±1.8 ys; Controls: 14.2±2.4 yrs</td>
<td>Postero-anterior and panoramic radiograph</td>
<td>The expanded maxillary arch was statistically associated with potential mandibular skeletal asymmetry.</td>
<td>Yes</td>
<td>5</td>
</tr>
<tr>
<td>Halicioglu</td>
<td>2014</td>
<td>Cross-sectional with control group</td>
<td>30 UPCB (15F, 15M)</td>
<td>95 sbj (57F, 38M); 29 BPCB (17F, 12M); 36 sbj control group (25F, 11M)</td>
<td>Dentistry patients</td>
<td>UPCB: 14.5±1.9 ys; PCB: 14.6±1.8 ys; Controls: 14.2±2.4 yrs</td>
<td>CBCT</td>
<td>There was no statistically significant difference in condylar height, ramal height, and condylar-ramal height measurements between the right and left sides of the UPCB group and control group.</td>
<td>No</td>
<td>8</td>
</tr>
<tr>
<td>Kasimoglu</td>
<td>2015</td>
<td>Cross-sectional with control group</td>
<td>30 UPCB (15F, 15M)</td>
<td>120 sbj (60F, 60M); 30 CL I (15F, 15M); 30 CL II (15F, 15M); 30 CL III (15F, 15M)</td>
<td>Patients Clinics of Pedodontology</td>
<td>Total sample: 11–16 ys (13.6±1.6)</td>
<td>Panoramic X-Rays</td>
<td>Patients with UPCB have asymmetric condylar heights. These patients might be at risk for developing skeletal mandibular asymmetries in the future.</td>
<td>Yes</td>
<td>8</td>
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<tr>
<td>Kiki</td>
<td>2007</td>
<td>Cross-sectional with control group</td>
<td>75 BPCB</td>
<td>150 (114F, 36M); 75 control group</td>
<td>Department of Orthodontics</td>
<td>Total sample: 11–17 ys; PCB: 14.2±1.9; Ctr: 14.7±2.3</td>
<td>Panoramic radiographs</td>
<td>The patients with posterior crossbite had more asymmetrical condyles than controls.</td>
<td>Yes</td>
<td>7</td>
</tr>
<tr>
<td>Kilic</td>
<td>2008</td>
<td>Cross-sectional with control group</td>
<td>UPCB: 81 (64F, 17M)</td>
<td>156 sbj (121F, 35M); 75 control group (37F, 18M)</td>
<td>School</td>
<td>Total sample: 11–17 ys; UPCB: 14.3±2.9; Ctr: 14.7±2.3</td>
<td>Panoramic radiographs</td>
<td>Condylar ramus and ramus height on crossbite side were significantly smaller than those of non-crossbite side. Condylar ramal and total asymmetry indexes were higher in the crossbite group than in the control group</td>
<td>Yes</td>
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Table 1. Continued

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<tr>
<td>Kusayama</td>
<td>2003</td>
<td>Cross-sectional with control group</td>
<td>PCB: not reported</td>
<td>44 sbj; 19 control group (8F, 11M)</td>
<td>Orthognathic Surgical patients</td>
<td>Total sample: mean age 21.1 ys</td>
<td>Frontal cephalometric and 3D dental model</td>
<td>A significantly high correlation between transverse dental anomalies and skeletal asymmetry was found.</td>
<td>Yes</td>
<td>6</td>
</tr>
<tr>
<td>Langberg</td>
<td>2005</td>
<td>Cross-sectional with control group</td>
<td>UPCB 15 (7F, 8M)</td>
<td>30 sbj; 15 control group (12F, 3M)</td>
<td>Orthodontic patients</td>
<td>UPCB: mean age 26.2 ys; control group 30.6 ys</td>
<td>Postero-anterior radiographs</td>
<td>Adult patients with UPCB had statistically significantly more transverse mandibular dental asymmetry.</td>
<td>Yes</td>
<td>7</td>
</tr>
<tr>
<td>O’Byrn</td>
<td>1995</td>
<td>Cross-sectional with control group</td>
<td>UPCB 30 (20F, 10M)</td>
<td>60 sbj; 30 control group (21F, 9M)</td>
<td>Orthodontic patients</td>
<td>UPCB: 28 ± 3 ys; Control: 27 ± 9 ys</td>
<td>Submental vertex radiographs</td>
<td>No statistically significant difference was found in condylar position within the two groups. Skeletally, the mandible showed no asymmetry.</td>
<td>No</td>
<td>8</td>
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<td>Pellizzi</td>
<td>2006</td>
<td>Cross-sectional with control group</td>
<td>UPCB: 15 (9F, 6M)</td>
<td>31 sbj (19F, 12M); 16 control group (10F, 6M)</td>
<td>Not reported</td>
<td>6–12.9 ys; UPCB: 9.3 ± 2.1 ys; Control: 9.6 ± 2.1 ys</td>
<td>Clinical examination and MRI</td>
<td>These findings suggest that temporomandibular joint derangements and functional UPCB are independent occurrences.</td>
<td>No</td>
<td>6</td>
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<tr>
<td>Pirttiniemi</td>
<td>1991</td>
<td>Observational study</td>
<td>PCB; 13 sbj (not reported gender)</td>
<td>49 sbj (34E, 15M); 36 normal lateral occlusion</td>
<td>Patients and students</td>
<td>Total sample: 15–33 ys; 24.2 ± 3.8 ys</td>
<td>Computed tomography</td>
<td>Significant asymmetry in condyle path in cases of lateral crossbites, which is connected with asymmetry in craniofacial skeleton and midline deviation.</td>
<td>Yes</td>
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<td>Primzic</td>
<td>2013</td>
<td>Prospective observational study</td>
<td>UPCB 78 (42F, 36M)</td>
<td>234 sbj (115F, 119M); 156 control group (73F, 83M)</td>
<td>Department of Orthodontics</td>
<td>Total sample: 3.9–11.9 ys</td>
<td>Three-dimensional laser scanning device</td>
<td>Children with unilateral functional CB exhibited a greater facial asymmetry than children without this malocclusion in all the dentition phases herein investigated.</td>
<td>Yes</td>
<td>7</td>
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<td>Primzic</td>
<td>2009</td>
<td>Prospective observational study</td>
<td>UPCB 30 (17F, 13M)</td>
<td>58 sbj (30M, 28F); 28 control group (11F, 17M)</td>
<td>Department of Paedodontics</td>
<td>UPCB: 3.6–6.6 ys, 4.9 ± 1 ys; Control: 4.8–6.1 ys, 5.3 ± 0.4 ys</td>
<td>Three-dimensional laser scanning device</td>
<td>The crossbite children had a statistically greater asymmetry of the face especially the lower third and a significant lower smaller palatal volume than normal occlusion group at baseline.</td>
<td>Yes</td>
<td>7</td>
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<tr>
<td>Takada</td>
<td>2015</td>
<td>Cross-sectional with control group</td>
<td>UPCB 15 (9F, 6M)</td>
<td>30 sbj (12M, 18F); 15 control group (9F, 6M)</td>
<td>Subjects seeking or treatment</td>
<td>UPCB: 23.5 ± 7.6 ys; Control: 22.8 ± 5.8 ys</td>
<td>Computed angiography, postero-anterior submentovertex</td>
<td>Facially asymmetric adult subjects with malocclusions associated with UPCB exhibit not only mandibular asymmetry but also remodelling of the condylar head and glenoid fossa that accompanies the three-dimensional shifting of the MHA.</td>
<td>Yes</td>
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Crossbite and EMG Activity

Eleven articles evaluated the association between posterior crossbite and EMG activity, all reporting a positive association. Hence,
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<td>Alarcon (25)</td>
<td>2009</td>
<td>Cross-sectional with control group</td>
<td>UPCB: 30 sbj</td>
<td>60 sbj (30 M, 30 F)</td>
<td>Pediatric Clinic</td>
<td>UPCB: 10–12 ys; Control group: 10–12 ys</td>
<td>Bilateral sEMG activity</td>
<td>During clenching, activity of the crossbite side masseter area was significantly lower in cases versus controls.</td>
<td>Yes</td>
<td>9</td>
</tr>
<tr>
<td>Alarcon (24)</td>
<td>2000</td>
<td>Cross-sectional with control group</td>
<td>UPCB: 30 (17F, 13M)</td>
<td>60 sbj (33 F, 27 M); 30 control group (16 F, 14 M)</td>
<td>Department of Odontology</td>
<td>UPCB: mean 12.2 ys; control group: mean 12.5 ys</td>
<td>Eight-channel electromyography</td>
<td>The posterior temporalis of the non-crossbite side was more active than that of the same side in subjects with crossbite at rest position and during swallowing. In addition, the activity of both anterior digastrics was higher in the crossbite subjects during swallowing. During chewing, the masseter muscle on the crossbite side was less active in the crossbite patients than in normocclusive subjects.</td>
<td>Yes</td>
<td>9</td>
</tr>
<tr>
<td>Andrade (49)</td>
<td>2010</td>
<td>Cross-sectional with control group</td>
<td>UPCB: 17 (not reported gender)</td>
<td>37 sbj; 20 control group (not reported gender)</td>
<td>Department of Pediatric Dentistry</td>
<td>Total sample: 7–10 ys; UPCB: 8.6 ± 1.2 ys control group: 8.6 ± 1.1 ys</td>
<td>EMG System</td>
<td>Balanced EMG activity of masseter and anterior temporalis muscles was observed only in the control group. These results indicate that in children, UPCB can alter the co-ordination of masticatory muscles during mastication.</td>
<td>Yes</td>
<td>6</td>
</tr>
<tr>
<td>Andrade (31)</td>
<td>2009</td>
<td>Cross-sectional with control group</td>
<td>UPCB: 20 (8 F, 12 M)</td>
<td>36 sbj (14 F, 22 M); 16 control group (6 F, 10 M)</td>
<td>Department of Pediatric Dentistry</td>
<td>UPCB: 8.8 ± 1 y; control group: 8.9 ± 1 y</td>
<td>EMG system</td>
<td>The masseter of the crossbite side was more active than that of the non-crossbite side in UPCB group during maximal clenching. The mean electric activity for masseter and temporal muscles at clench was lower in the UPCB group than in the control group. Mean muscle activity at rest showed how the UPCB group presented lower activation of masseters than the control group.</td>
<td>Yes</td>
<td>7</td>
</tr>
<tr>
<td>Ciavarella (50)</td>
<td>2012</td>
<td>Cross-sectional with control group</td>
<td>UPCB 15 sbj</td>
<td>30 sbj (14 M, 16 F); 15 control group (7 F, 8 M)</td>
<td>Orthodont Department</td>
<td>UPCB: mean 11.5 ys; control group: mean 12 y</td>
<td>sEMG</td>
<td>Yes</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>Author</td>
<td>Year</td>
<td>Study design</td>
<td>Crossbite</td>
<td>Sample</td>
<td>Age</td>
<td>Measurements</td>
<td>Results</td>
<td>Association</td>
<td>Score</td>
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<tr>
<td>Ferrario (23)</td>
<td>1999</td>
<td>Cross-sectional with control group</td>
<td>UPCB 10 sbj (6F, 4M)</td>
<td>30 sbj (14M, 16F); 20 control group (10F, 10M)</td>
<td>16-18 yrs; UPCB 17.3±0.8 yrs; control group 17.4±0.6 yrs</td>
<td>Four-channel EMG</td>
<td>In the crossbite subjects, the four analyzed muscles appeared to contract with altered and asymmetric relationship of the masticatory muscles during chewing on both sides. Compared with children with a normal occlusion, the children with a forced bite (9 sbj) showed a significant greater activity of the anterior temporal muscle on the side of forced bite, while that in the posterior temporalis on the non-forced bite side in children with large lateral deviation was lower. Compared with children with normal occlusion, the children with a forced bite had lower amplitude in the anterior and posterior temporalis on the non-forced bite side during chewing.</td>
<td>Yes</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>Ingervall (22)</td>
<td>1975</td>
<td>Observational study</td>
<td>16 UPCB with mandibular shift</td>
<td>19 sbj (11F, 8M) with mandibular shift without UPCB: 12 sbj (7F, 5M)</td>
<td>Note reported</td>
<td>Three-channel sEMG</td>
<td>Compared with children with normal occlusion the entire group of children with forced bite (19 sbj) showed a significant greater activity of the anterior temporal muscle on the side of forced bite, while that in the posterior temporalis on the non-forced bite side in children with large lateral deviation was lower. Compared with children with normal occlusion, the children with a forced bite had lower amplitude in the anterior and posterior temporalis on the non-forced bite side during chewing.</td>
<td>Yes</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Moreno (51)</td>
<td>2008</td>
<td>Observational study</td>
<td>7% (3) of the sample (not reported gender)</td>
<td>45 sbj (33F, 12M)</td>
<td>22-29 yrs, mean: 24 yrs</td>
<td>8 channels sEMG recordings</td>
<td>Despite the low frequency of a PCB in this sample, it has demonstrated an important effect upon the activity of ipsilateral masseter in maximum clenching. The major force is produced by the anterior temporalis, which remains nearly inactive.</td>
<td>Yes</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Author</td>
<td>Year</td>
<td>Study design</td>
<td>Crossbite</td>
<td>Sample</td>
<td>Selected from</td>
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<tr>
<td>Piancino (52)</td>
<td>2009</td>
<td>Cross-sectional with control group</td>
<td>PCB: 82 (not reported gender)</td>
<td>94 sbj; 12 control group</td>
<td>Orthod Department</td>
<td>UPCB: 8.6 ± 1.3 ys; control group: 8.9 ± 0.6 ys</td>
<td>Multichannel electromyography</td>
<td>Muscle activity during mastication on the non-affected side is normal, whereas on the crossbite side muscle activity during mastication is altered both in reverse and non-reverse cycles. The masster of the non-affected side is, in general, more loaded than in healthy controls, whereas the masster of the crossbite side is less active.</td>
<td>Yes</td>
<td>7</td>
</tr>
<tr>
<td>Tecco (53)</td>
<td>2010</td>
<td>Cross-sectional with control group</td>
<td>75 PCB (30F, 45M); 50 UPCB; 25 BPCB</td>
<td>100 sbj (36F, 64M); 25 control group (6F, 19M)</td>
<td>Patients and dentistry students.</td>
<td>UPCB: 19.9 ± 4.4 ys (mean M/F); BPCB: 20.4 ± 4.3 ys; control group: 22.5 ± 5.8 ys</td>
<td>sEMG</td>
<td>In the mandibular rest position, patients with UPCB showed a significant difference in sEMG activity of the anterior temporal muscle. During maximum voluntary clenching, control subjects showed significantly lower sEMG activity in both the sternocleidomastoid and the posterior cervical muscles compared with patients demonstrating both unilateral and bilateral crossbites.</td>
<td>Yes</td>
<td>8</td>
</tr>
<tr>
<td>Woźniak (54)</td>
<td>2015</td>
<td>Cross-sectional with control group</td>
<td>UPCB and ssTMD: 50 (22F, 28M)</td>
<td>150 sbj (74M, 76F); 100 malocclusion pz (54F, 46M)</td>
<td>Patients</td>
<td>UPCB and TMDss: 20.8 ± 1.1 ys; Malocclusion pz: 21.4 ± 1 ys</td>
<td>sEMG</td>
<td>The results confirmed the influence of unilateral posterior crossbite on variations in spontaneous muscle activity in the mandibular rest position and maximum voluntary contraction. In addition, there was a significant increase in the Asymmetry Index and Torque Coefficient, responsible for a latero-deviating effect on the mandible caused by unbalanced right and left masster and temporal muscles.</td>
<td>Yes</td>
<td>7</td>
</tr>
</tbody>
</table>

Crossbite = number of subjects in the sample presenting crossbite; PCB = posterior crossbite; UPCB = unilateral posterior crossbite; BPCB = bilateral posterior crossbite; Sbj = subjects; Ctr = control group; sEMG = surface electromyography; Ys = years; ssTMD = subjective symptoms of temporomandibular dysfunction.
### Table 3. Crossbite and bite force.

<table>
<thead>
<tr>
<th>Author</th>
<th>Year</th>
<th>Study design</th>
<th>Crossbite</th>
<th>Sample</th>
<th>Selected from</th>
<th>Age</th>
<th>Methods/Measurements</th>
<th>Results</th>
<th>Association</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Sonnesen (55)</td>
<td>2001</td>
<td>Cross-sectional with control group</td>
<td>UPCB 26 (13E, 13M)</td>
<td>52 sbj (26F, 26M); 26 control group (13E, 13M)</td>
<td>Dental health service</td>
<td>UPCB: 7–13 ys (9.35 mean); control group: corresponding age</td>
<td>Pressure transducer</td>
<td>Differences in the muscle function associated with unilateral crossbite lead to a significantly smaller bite force in the crossbite group compared with controls and this difference did not diminish with age and development.</td>
<td>Yes</td>
<td>9</td>
</tr>
<tr>
<td>2 Castelo (56)</td>
<td>2007</td>
<td>Cross-sectional with control group</td>
<td>21 UPCB (12E, 9M); PCB 10 (4F, 6M); MCB 11 (8F, 3M)</td>
<td>49 sbj (26M, 23F); PNO: (5F, 10M); MNO: (7F, 6M)</td>
<td>Department of Pediatric Dentistry</td>
<td>Aged 3.5–7 yrs; PCB (60.5 ms); MCB (71.9 ms); PNO (58.7 ms); MNO (72.8 ms)</td>
<td>Pressure transducer</td>
<td>A statistical difference in bite force was observed between the MNO and MCB groups, with greater values for the MNO subjects.</td>
<td>Yes</td>
<td>7</td>
</tr>
<tr>
<td>3 Castelo (57)</td>
<td>2010a</td>
<td>Cross-sectional with control group</td>
<td>35 sbj (15M, 20F); PCB 19 (9F, 10M); MCB 16 (11F, 3M)</td>
<td>67 sbj (36M, 31F); PNO 19 (5F, 14M); MNO 13 (6F, 7M)</td>
<td>Department of Pediatric Dentistry</td>
<td>Aged 3.5–7 yrs; PCB (59.5 ms); MCB (73.2 ms); PNO (58.4 ms); MNO (72.4 ms)</td>
<td>Pressure transducer</td>
<td>The MCB group presented bite force values significantly smaller than group MNO.</td>
<td>Yes</td>
<td>7</td>
</tr>
<tr>
<td>4 Rentes (58)</td>
<td>2002</td>
<td>Cross-sectional with control group</td>
<td>Number not reported</td>
<td>30 sbj</td>
<td>Dental school</td>
<td>3.5–5 yrs range</td>
<td>Pressure transducer</td>
<td>There were no significant statistical differences among crossbite group and control group.</td>
<td>No</td>
<td>4</td>
</tr>
</tbody>
</table>

Crossbite = number of subjects in the sample presenting crossbite; UPCB = unilateral posterior crossbite; Sbj = subjects; Ctr = control group; PCB = primary crossbite; MCB = mixed-crossbite; PNO = primary normal occlusion; MNO = mixed-normal occlusion; Ms = months; ys = years.

### Table 4. Crossbite and masticatory muscle thickness.

<table>
<thead>
<tr>
<th>Author</th>
<th>Year</th>
<th>Study design</th>
<th>Crossbite</th>
<th>Sample</th>
<th>Selected from</th>
<th>Age</th>
<th>Methods/Measurements</th>
<th>Results</th>
<th>Association</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Andrade (31)</td>
<td>2009</td>
<td>Cross-sectional with control group</td>
<td>UPCB 20 (8F, 12M)</td>
<td>36 sbj (22M, 14F); 16 NOccl group (6F, 10M)</td>
<td>Dental patients</td>
<td>Total sample: 7–10ys; UPCB: 8.8 ± 1.1 ys; NOccl: 8.8 ± 1.1 ys</td>
<td>Ultrasonography at rest and during maximal clenching</td>
<td>The ultrasonographic evaluation (thickness of the masseter and anterior temporalis) did not show statistically significant differences between groups nor between sides in the PCB and NOccl groups.</td>
<td>No</td>
<td>7</td>
</tr>
<tr>
<td>2 Castelo (14)</td>
<td>2010b</td>
<td>Cross-sectional with control group</td>
<td>35 UPCB (15M, 20F); 19 PCB (9F, 10M); MCB 11 (5F, 5M); 21 UPCB (12E, 9M); PCB 10 (4F, 6M); MCB 11 (8Fexgs, 3M)</td>
<td>81 sbj; 19 PNO (4F, 15M); 27 MNO (9F, 18M); 49 sbj (26M, 23F); PNO: (5F, 10M); MNO (7F, 6M)</td>
<td>Department of Pediatric Dentistry</td>
<td>Total sample: 64.7 ± 7 m</td>
<td>Ultrasonography at rest and during maximal clenching</td>
<td>The results showed that muscle thickness did not differ significantly between the sides of the dental arches in all groups. The anterior temporalis thickness at rest was statistically thicker for the crossbite side than the normal side in the MCB group.</td>
<td>No</td>
<td>7</td>
</tr>
<tr>
<td>3 Castelo (56)</td>
<td>2007</td>
<td>Cross-sectional with control group</td>
<td>38 UPCB (17M, 21F)</td>
<td>28.2 sbj; 16 BPCB; 224 control group (112F, 112M)</td>
<td>Department of Orthodontics</td>
<td>Aged 3.5–7 yrs; PCB (60.5 ms); MCB (71.9 ms); PNO (58.7 ms); MNO (72.8 ms); UPCB: 11.9 ys mean (8.1–17.8 ys); Control group: 12 ys mean (7.2–18.2 ys)</td>
<td>Ultrasonography at rest and during maximal clenching</td>
<td>In the UPCB group, the thickness of the masseter muscle on the crossbite side was statistically significantly thinner than the one on the normal side.</td>
<td>Yes</td>
<td>7</td>
</tr>
<tr>
<td>4 Kiliaridis (26)</td>
<td>2007</td>
<td>Cross-sectional with control group</td>
<td>38 UPCB (17M, 21F)</td>
<td>28.2 sbj; 16 BPCB; 224 control group (112F, 112M)</td>
<td>Department of Orthodontics</td>
<td>Aged 3.5–7 yrs; PCB (60.5 ms); MCB (71.9 ms); PNO (58.7 ms); MNO (72.8 ms); UPCB: 11.9 ys mean (8.1–17.8 ys); Control group: 12 ys mean (7.2–18.2 ys)</td>
<td>Ultrasonography at rest and during maximal clenching</td>
<td>In the UPCB group, the thickness of the masseter muscle on the crossbite side was statistically significantly thinner than the one on the normal side.</td>
<td>Yes</td>
<td>8</td>
</tr>
</tbody>
</table>

Crossbite = number of subjects in the sample presenting crossbite; PCB = posterior crossbite; UPCB = unilateral posterior crossbite; BPCB = bilateral posterior crossbite; Sbj = subjects; Ctr = control group; NOccl = normal occlusion; PCB = primary crossbite; MCB = mixed-crossbite; PNO = primary normal occlusion; MNO = mixed-normal occlusion; Ms = months; ys = years.
<table>
<thead>
<tr>
<th>Author</th>
<th>Year</th>
<th>Study design</th>
<th>Crossbite</th>
<th>Sample</th>
<th>Selected from</th>
<th>Age</th>
<th>Methods/Measurements</th>
<th>Results</th>
<th>Association</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Andrade (49)</td>
<td>2010</td>
<td>Cross-sectional with control group</td>
<td>17 UPCB (not reported gender; 5 on the R, 12 on the L)</td>
<td>37 sbj; 20 control group (not reported gender)</td>
<td>Dental patients</td>
<td>Total sample: 7–10 yrs; UPCB: 8.6 ± 1.2 yrs; Control group: 8.6 ± 1.1 yrs</td>
<td>Visual spot-checking method</td>
<td>Children with and without UPCB presented a bilateral masticatory pattern with similar chewing rate and cycle duration.</td>
<td>No</td>
<td>6</td>
</tr>
<tr>
<td>Martín (59)</td>
<td>2000</td>
<td>Cross-sectional with control group</td>
<td>30 right PCB (17F, 13M; all on the R)</td>
<td>60 sbj (33F, 27M); 30 control group (16F, 14M)</td>
<td>Department of Odontology</td>
<td>Total sample: 10–14 yrs; UPCB: 12.2 yrs mean; Control group: 12.5 yrs mean.</td>
<td>Kinesiograph</td>
<td>No differences were found in the parameters of the masticatory cycle between groups. There was no relationship between the side of the crossbite and the masticatory preference side.</td>
<td>No</td>
<td>9</td>
</tr>
<tr>
<td>Miyawaki (60)</td>
<td>2004</td>
<td>Cross-sectional with control group</td>
<td>12 UPCB (6F, 6M); 24 sbj (12F, 12M); 12 control group (6F, 6M)</td>
<td>Orthod Department</td>
<td>Total sample: 18–30 yrs; UPCB: 23.8 yrs mean; Control group: 22.9 yrs mean</td>
<td>Optoelectronic jaw-tracking system</td>
<td>The lateral and medial poles of the condyle on the crossbite side moved more in the medial direction and less in the lateral direction during mastication in the crossbite patients than the condyle in the normal subjects.</td>
<td>Yes</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>Nie (27)</td>
<td>2010</td>
<td>Cross-sectional with control group</td>
<td>16 PCB (Not reported gender; Not reported side)</td>
<td>128 sbj (43M, 85F); 106 CB (36M, 70F); 22 control group (15F, 7M)</td>
<td>Orthod Department</td>
<td>CB: 12–35 yrs range; Control group: 16–30 yrs range</td>
<td>Kinesiograph</td>
<td>In the crossbite groups, normal chewing occurred much less often than in subjects with normal occlusion. In the crossbite or shift side, reverse type and reverse-crossing type occurred more often than in contralateral side.</td>
<td>Yes</td>
<td>8</td>
</tr>
<tr>
<td>Piancino (52)</td>
<td>2009</td>
<td>Cross-sectional with control group</td>
<td>82 UPCB (not reported gender; 50 on the R, 32 on the L)</td>
<td>94 sbj; 12 control group</td>
<td>Orthod Department</td>
<td>UPCB: 8.6 ± 1.3 yrs; Control group: 8.9 ± 0.6 yrs</td>
<td>Kinesiograph</td>
<td>The reverse cycles on the crossbite side were narrower with respect to the cycles on the non-affected side.</td>
<td>Yes</td>
<td>8</td>
</tr>
<tr>
<td>Rilo (61)</td>
<td>2007</td>
<td>Cross-sectional with control group</td>
<td>25 UPCB (21F, 4M; 12 on the R, 13 on the L)</td>
<td>50 sbj (40F, 10M); 25 control group (19F, 6M)</td>
<td>University students</td>
<td>UPCB: 17–26 yrs range; 19.6 yrs mean; Control group: 20–26 yrs range</td>
<td>Gnathograph</td>
<td>Patients with UPCB showed a higher proportion of reverse-sequencing patterns during chewing on the crossbite side compared with that on the non-crossbite side and that for the control group. Abnormal cycles on the crossbite side were more frequent when two or more teeth are involved than when only one tooth was involved.</td>
<td>Yes</td>
<td>8</td>
</tr>
<tr>
<td>Sever (28)</td>
<td>2010</td>
<td>Cross-sectional with control group</td>
<td>20 UPCB (14F, 6M; 11 on the R, 9 on the L)</td>
<td>30 sbj (19F, 11M); 10 control group (5F, 5M)</td>
<td>Pedodontic Clinic</td>
<td>UPCB: 5 ± 1.2 yrs; Control group: 5.3 ± 1.3 yrs</td>
<td>Sirognathography (COSIG II)</td>
<td>Children with a UPCB produced chewing cycles with a shorter rest position and more frequently in a reverse direction when chewing on the UPCB side in comparison with children with a normal occlusion and with the non-UPCB side.</td>
<td>Yes</td>
<td>6</td>
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</tbody>
</table>

Crossbite = number of subjects in the sample presenting crossbite; CB = anterior and/or posterior crossbite; PCB = posterior crossbite; UPCB = unilateral posterior crossbite; BPCB = bilateral posterior crossbite; Sbj = subjects; Ctr = control group; R = right side; L = left side; ys = years.
according to the currently available scientific data, UPCB is associated to masticatory muscle EMG asymmetric activity. In particular, Alarcón et al. (24) found that in posterior crossbite subjects, the contralateral posterior temporalis showed higher EMG activity than the ipsilateral one, possibly as a consequence of functional mandibular shift in order to reach an occlusal stability (24, 31). Nevertheless, it must be stressed that asymmetric EMG activity does not mean pathology. Indeed, the same authors found that the right anterior temporal demonstrated a higher EMG activity than the left anterior temporal in the normocclusive group, suggesting that muscular asymmetry could be considered physiological and compatible with normal function (9, 24, 31). Furthermore, the lack of consistency also in the studies reporting an association between posterior crossbite and EMG asymmetry has to be stressed. Indeed, Alarcón et al. (24) even reporting the crossbite side to be less active than in normocclusive subjects, did not find any difference between the crossbite side and non-crossbite side. Instead, Andrade et al. (31) found that the masseter of the crossbite side was more active than that of the non-crossbite side in the UPCB group during maximal clenching. Conversely, Piancino et al. (52) reported a reduced masseter activity on the crossbite side and unaltered or increased on the non-crossbite side.

All the analyzed studies used surface EMG measurements to evaluate muscle activity. Some studies reported good reproducibility and sufficient accuracy in young subjects (72, 73). Nevertheless, several authors reported very large standard deviations in EMG activity, both in subjects with and without crossbite (23, 25, 74). This wide inter-individual variability should be taken into account when interpreting the results. Finally, surface EMG does not allow the activity of a single muscle to be recorded due to the so-called cross-talking of the neighbouring muscles (25).

Crossbite and Bite Force
Four articles evaluated the association between posterior crossbite and bite force. A positive association is supported by 75% of the analyzed studies. It must be stressed that three out of four studies were published by the same research group, with samples of similar age, but opposite results (56–58). Interestingly, the only study reporting ‘no association’ (58) is older than the others and of low scientific and methodological quality.

All studies analyzed children/adolescents, ranging from 3.5 to 13 years, using a pressure transducer to record bite force. No information is available on adults on this topic. According to these data, UPCB might lead to a significantly smaller bite force compared with non-crossbite subjects, and this difference does not decrease with age and development (55). Nevertheless, no definitive conclusion can be drawn on this topic, as a consequence of the insufficient evidence available.

Crossbite and Masticatory Muscle Thickness
Four studies analyzed the association between UPCB and masticatory muscle thickness, half of them reporting a significant association and half of them not. Indeed, Kiliasidis et al. (26) reported that in UPCB subjects the thickness of the masseter muscle was significantly thinner on the crossbite side, with no significant differences in the non-crossbite group. On the other hand, Andrade et al. (31) found no differences either between sides or between UPCB and no-UPCB groups. Interestingly, the opposite findings were reported by the same authors in different studies in a three-year time lapse. This could be ascribed to the different sample size of the studies. Hence, no conclusions can currently be drawn on UPCB and muscle thickness.

All the analyzed studies used similar methods, i.e. ultrasonography investigation. Nevertheless, 3 selected children ranging from 4 to 6 years old, whereas Kiliasidis et al. (26) used a sample of adolescents ranging from 8 to 18 years old.

Crossbite and Chewing Cycle
Seven articles evaluated the association between posterior crossbite and chewing cycle. According to most of the studies (27, 28, 52, 60, 61), subjects with UPCB present different kinematics of the mandible during mastication when chewing on the affected side, compared with no-UPCB subjects. Indeed, during chewing, the mandible deviates laterally towards the bolus side and then medially during closure (52). Sometimes, the mandible can first deviate medially and then laterally, thus ensuring overlap of opposing dental occlusal surfaces. This is called a ‘reverse chewing cycle’. Reverse chewing cycles show an abnormal, narrow pattern characterized by smaller lateral displacement and slower velocity of the mandible in comparison with normal chewing. In a patient with unilateral crossbite, reverse cycles occur mainly on the crossbite side, although not all cycles are reverse when chewing from the crossbite side (52). Nevertheless, the reverse chewing cycle is very common in children with a normal occlusion (33), who present a smaller lateral component during opening and closing than adults. According to the authors, the reverse cycle is not abnormal because normal children with primary dentition have a smaller lateral component and difficulty in controlling asymmetric muscle activity. Hence, reverse chewing cycles cannot be considered pathologic but could be a physiologic and common feature of the chewing cycle in children.

A limit of the present review is that, in order to enhance the methodological rigor of the studies examined and the conclusion drawn, only articles in peer-reviewed journals and in English were included. Nevertheless, according to this strategy, publications in other languages and/or publications reported in different databases may have been unjustly excluded in our review.

Conclusions

1. Most studies currently available report a skeletal asymmetric growth in UPCB subjects; EMG activity of masticatory muscles has been reported to be different between the crossbite side and non-crossbite sides; UPCB might lead to a significantly smaller bite force compared with non-crossbite subjects; there is no evidence of masticatory muscle thickness asymmetry; and UPCB is reported to be associated to an increase in the reverse chewing cycle.

2. No definitive conclusion can be drawn on the relationship between posterior crossbite and skeletal asymmetry. The overwhelming majority of the studies analyzed, both reporting and not reporting association, are of medium–low scientific and methodological quality. The possible association should be addressed by future research, with rigorous scientific methodology (see Strobe Statement checklist).

3. Very few studies on the topic report long-term data, limiting the evidence on the topic and making it impossible to understand whether the posterior crossbite is a cause, an effect, or unrelated to skeletal and muscular asymmetries. Future surveys with long-term control are needed, especially in adolescent samples.

4. Finally, it is very important to stress that, even if a significant association between UPCB, skeletal, and functional asymmetries has been reported elsewhere, a certain amount of asymmetry has to be considered physiologic and present in all subjects.
Supplementary material

Supplementary material is available at European Journal of Orthodontics online.

References

G. Iodice et al.