A 2D ultrasound evaluation of swallowing in children with unilateral posterior crossbite

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SUMMARY

BACKGROUND: Swallowing pattern is important in the aetiology of unilateral posterior crossbite (ULCB). The aim of this study was to assess the swallowing pattern and tongue function during swallowing in children with ULCB in deciduous dentition using B-mode and M-mode ultrasonography.

MATERIALS AND METHODS: Twenty-three children with ULCB, aged 4.1–6.6 years, and 22 children without ULCB, 5.7–6.7 years, were examined with simultaneous B- and M-mode ultrasonography. The swallowing pattern was assessed according to the action of genioglossus muscle in ultrasound images with the scan line of the ultrasound transducer set through the tongue tip. The tongue movements (duration, range, and speed) were compared within each subphase (I, IIA, IIB, IIIA, and IIIb) and in the entire swallowing cycle between the children with ULCB and without ULCB.

RESULTS: The visceral swallowing pattern was found in 83 per cent of children with ULCB and in 36 per cent of children without ULCB; the difference was statistically significant. The duration of phase IIb and the entire swallowing act was found to be statistically significantly prolonged in the ULCB group. Furthermore, the range of the tongue movement in phases and in the entire swallowing act was statistically significantly larger in the ULCB group. The speed of the tongue movement was statistically significantly higher in the ULCB group in phase IIA.

CONCLUSIONS: The 2D ultrasonography was used to evaluate the prevalent type of swallowing in children with ULCB. Visceral type of swallowing pattern and the changed tongue function during swallowing seem to be important factors in the aetiology of ULCB.

Introduction

Unilateral posterior crossbite (ULCB) is one of the most prevalent malocclusions in the early stage of dental development and is reported to occur between 8.7 and 23.3 per cent depending on the population sampled (Thilander et al., 1984; Kurol and Berglund, 1992; Thilander and Lennartsson, 2002; Ovsenik, 2009; Dimberg et al., 2013). The aetiology of ULCB can be in general assigned to heredity and environmental influences. The main causative factor in ULCB development is reduction in the width of the maxillary arch in comparison with mandibular arch (Allen et al., 2003; Primozic et al., 2009, 2013) as a result of sucking habits (Larsson, 1986; Ogaard et al., 1994; Warren and Bishara, 2002; Melink et al., 2010), mouth breathing, incompetent lip seal (Bresolin et al., 1983; Behlfelt et al., 1989; Kerr et al., 1989), and visceral swallowing pattern with incorrect tongue posture on the mouth floor (Hanson and Cohen, 1973; Melsen et al., 1979, 1987; Ghafari et al., 1988; Melink et al., 2010).

Assessment of tongue posture and function can be performed by clinical examination and is an important part of functional diagnostics in orthodontics. Observation of tongue movements during swallowing with lips apart is the simplest method for diagnosing the visceral type of swallowing; however, a mere touch of lips can disturb the examinee to protrude the tongue forward and swallow viscerally (Perry, 1972; Peng et al., 2003, 2004). Another method with palpation of the temporals and masseter muscles during swallowing was proposed (Melsen et al., 1987; Ovsenik et al., 2007). Unfortunately, clinical examination does not enable objective evaluation due to anatomical limitation (Mehnert et al., 2009). Additional methods for observation of the tongue were developed and used. Many studies used cineradiography (Cleall, 1965; Milne and Cleall, 1970; Fujiki et al., 2004), electropalatography (Ichida et al., 1999), electromagnetic articulography (Schwestka-Polly et al., 1992), computer tomography (Lowe et al., 1986), and magnetic resonance (Schwestka-Polly et al., 1995), but due to many reasons, especially the risk of irradiation did not prove appropriate for observation of the tongue in small growing children.

Simultaneous B- and M-mode ultrasonography enabled precise determination of the tongue function in a time diagram (Peng et al., 1995). The scan line for the M-mode can...
be set through the tip of the tongue (Peng et al., 2003) or in the middle of the tongue (Peng et al., 2004). In the M-mode diagram with scan line set through the tip of the tongue, the tip of the tongue and the genioglossus muscle can be observed and the swallowing pattern can be determined.

Cheng et al. (2002) examined the tongue function during swallowing and found that the tongue movements during swallowing are related to dentofacial morphology. It has been evaluated by Ovsenik et al., (2007), Ovsenik (2009), Melink et al., (2010) that the tongue plays an important role in the aetiology of ULCB. However, there is lack of scientific evidence in the assessment of swallowing pattern in small growing children because clinical examination of the tongue function is very limited due to anatomical structures surrounding the tongue and the assessment is therefore highly subjective. Furthermore, there were no reports in the literature on examinations of the tongue movements during swallowing in the primary dentition period using the 2D ultrasonography. Therefore, the aim of our study was to assess the prevalent swallowing pattern and to analyse the function of the tongue during swallowing in children with ULCB and in children without ULCB using B-mode and M-mode ultrasonography.

**Subjects and methods**

The research was approved by the Ethics Committee, Faculty of Medicine, University of Ljubljana, Slovenia, Number 22p/02/07, and the parents were asked to give informed consent to participate in the study.

Twenty-three children (13 girls and 10 boys) with ULCB, aged 4.1–6.6 years (mean 5.4 ± 0.8 years) were included in the ULCB group. Only the children in primary dentition period with all the posterior teeth in crossbite on one side and a midline deviation of at least 2 mm were included. The functional mandibular shift was clinically assessed by an experienced orthodontist (MO). The ULCB children did not have any signs or symptoms of temporomandibular disorders. The non-ULCB group of children consisted of 22 randomly selected children (10 girls and 12 boys) without morphological malocclusion, aged 5.7–6.7 years (mean 6.1 ± 0.3 years; Figure 1).

All the children were examined with B-mode and M-mode ultrasound techniques (Diagnostic Ultrasound System SSA-770A equipped with 3.5 MHz 100 degree convex transducer; Toshiba Medical Systems Corporation, Shimoishigami, Otawara, Japan). Ultrasound diagnostics was performed by an experienced radiologist (MMM). The head of each child was immobilized on a dental chair with a strap, with the Frankfurt horizontal line parallel to the floor (Figure 2). The transducer was positioned in the midsagittal line of the mouth floor skin. The children were asked to drink 5 ml of water from a syringe (Figure 2), to wait for at least 30 seconds, and then spontaneously swallow again. The procedure was repeated four times. The scan line for the M-mode was set in the middle of the tongue for the first three swallowing cycles (Peng et al., 1995, 2004; Cheng et al., 2002) and through the tip of the tongue in the last swallowing cycle (Peng et al., 2003). The ultrasound signals were recorded directly on a hard disc and analysed using the program eFilm Workstation 2.1.0, Merge Technologies Inc. Each M-mode screen with the scan line set in the middle of the tongue was analysed using the methodology by Cheng et al.
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(2002; Figure 3). The analysis was performed by an experienced radiologist (MMM) and an orthodontist (JV). Average values of all three swallowing acts and of the two examiners were used for the statistical analysis. The swallowing pattern was determined according to the action of the genioglossus muscle described by Peng et al. (2003; Figure 4). The data

Figure 3  B- and M-mode ultrasonogram of the tongue with the scan line of the ultrasound probe set in the middle of the tongue and schematic presentation of swallowing phases (I, Ila, I Ib, IIIa, and IIIb; Peng et al., 1995). The schematic presentation of swallowing phases is presented. In the rest phase (R), the tongue tip is usually positioned on the lingual surfaces of incisors or is touching the incisive papilla. The swallowing act starts with the shovel phase (I), in which the tongue tip moves cranially, the middle third of the tongue becomes concave and this is reflected in the down-movement of the curve in the M-mode ultrasonogram. In the early transport phase (Ila), the tongue is moving cranially and distally, the middle third of the tongue is approaching the hard palate, and therefore the concavity is disappearing. The late transport phase (I Ib) is characterized by minimal vertical movement of the tongue because of the distal transportation of saliva. In the early final phase (IIIa), the curve in the M-mode ultrasonogram drops because of the lowering of the mouth floor. In the late final phase (IIIb), the tongue returns to the rest position and this is reflected as a rise in the M-mode curve (Peng et al., 1995).

Figure 4  B- and M-mode ultrasonograms of tongue with the scan line of the ultrasound probe set through the tip of the tongue. There is an upward movement of the tongue tip and the genioglossus muscle in the M-mode image in the Figure 4a, which is characteristic for the somatic swallowing pattern. A downward movement of the tip of the tongue and the genioglossus muscle can be observed in the Figure 4b, which is characteristic for the visceral swallowing pattern.
were analysed by using the statistical program SPSS 17.0 (SPSS Inc., Chicago, Illinois, USA). The data of both groups of children were compared by using the Pearson’s chi-square test and Student’s t-test, and the statistical significance was set at \( P < 0.05 \). Intra-examiner reliability for assessment of the swallowing pattern and measurements in ultrasound images was investigated on 10 randomly selected children (5 from the ULCB group and 5 from the non-ULCB group) by the same examiner with a 7 day interval. Inter-examiner reliability for two examiners was also investigated. The intraclass correlation coefficient (ICC) was calculated for these measurements. Landis and Koch (1977) interpretation for ICC was used, i.e. ICC values below 0 indicated no agreement, 0–0.20 slight, 0.21–0.40 fair, 0.41–0.60 moderate, 0.61–0.80 substantial, and 0.81–1 almost perfect agreement.

### Results

The visceral swallowing pattern was found in 83 per cent of ULCB children and also in 36 per cent of children without ULCB. The difference was statistically significant (\( P = 0.002 \)).

Figures 5–7 represent mean and standard deviations of duration, range, and speed for each of the five swallowing phases and for the entire swallowing act in each group of children. In the ULCB group, the duration of phase IIb (\( P = 0.001 \)) and the entire swallowing act (\( P < 0.001 \)) was statistically significantly prolonged. Furthermore, range of the tongue movement in phases I (\( P = 0.027 \)), IIa (\( P < 0.001 \)), IIb (\( P = 0.037 \)) as well as in the entire swallowing act (\( P < 0.001 \)) was statistically significantly larger. Speed of the tongue movement was statistically significantly higher in the ULCB group in phase IIa (\( P = 0.019 \)).

The ICC for two examiners and for one examiner for assessment of the swallowing pattern was 1 (perfect agreement). The ICCs for duration and range of the swallowing phases and the entire swallowing act for two examiners and for one examiner are presented in Table 1. There was almost perfect agreement in all the phases except in the phase IIb (substantial agreement) for two examiners. For one examiner, substantial agreement was found for the range of phases I and IIb; all the other variables showed almost perfect agreement.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Inter-examiner reliability</th>
<th>Intra-examiner reliability</th>
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</thead>
<tbody>
<tr>
<td>Duration of phase I</td>
<td>0.83</td>
<td>0.93</td>
</tr>
<tr>
<td>Duration of phase IIa</td>
<td>0.92</td>
<td>1.00</td>
</tr>
<tr>
<td>Duration of phase IIb</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>Duration of phase IIIa</td>
<td>0.91</td>
<td>0.91</td>
</tr>
<tr>
<td>Duration of phase IIIb</td>
<td>0.81</td>
<td>0.98</td>
</tr>
<tr>
<td>Duration of the entire swallowing act</td>
<td>0.95</td>
<td>0.99</td>
</tr>
<tr>
<td>Range in phase I</td>
<td>0.91</td>
<td>0.80</td>
</tr>
<tr>
<td>Range in phase IIa</td>
<td>0.98</td>
<td>0.91</td>
</tr>
<tr>
<td>Range in phase IIb</td>
<td>0.61</td>
<td>0.69</td>
</tr>
<tr>
<td>Range in phase IIIa</td>
<td>0.84</td>
<td>0.87</td>
</tr>
<tr>
<td>Range in phase IIIb</td>
<td>0.93</td>
<td>0.99</td>
</tr>
<tr>
<td>Range in the entire swallowing act</td>
<td>0.88</td>
<td>0.87</td>
</tr>
</tbody>
</table>

### Discussion

There is generally no ideal swallowing pattern valid for everyone, but ideal swallowing pattern can be determined according to each developmental stage of the dentition. During years of growth and development from birth to adulthood, two different swallowing patterns can be registered, visceral and somatic (Ovsenik, 2010).

There has been very little evidence in the literature about the maturation of swallowing pattern in small growing children. Graber et al. (1985) reported that children after the age of 4 years, when the visceral swallowing pattern should mature and become somatic (Graber et al., 1985), more often swallow viscerally. One of the main reasons for swallowing pattern to mature later in the period of growth and development is sucking habits that have a direct effect on the developing occlusion as well as an indirect one due to a change in the swallowing pattern (Melsen et al., 1987; Ovsenik et al., 2007) and was found to be an important aetiological factor for ULCB development (Hanson and Cohen, 1973; Melsen et al., 1979; Ovsenik, 2009; Seemann et al., 2011). This study showed that significantly more children with ULCB swallowed viscerally in comparison with the non-ULCB group (non-ULCB group 36 per cent, ULCB group 83 per cent, \( P = 0.002 \)). The results are comparable with the results of the study by Ovsenik (2009) using the assessment of the swallowing pattern proposed by Melsen et al. (1987) with palpation of the masseter and the temporals muscles. It was determined that 35 per cent of 5-year-old children with normal deciduous dentition and 63 per cent of children with ULCB swallowed viscerally. At the age of 3 years, the atypical swallowing pattern was present in the same percentage of children regardless of the malocclusion present (with and without ULCB), whereas from the ages of 3–5 years, the atypical swallowing pattern significantly decreased in the non-ULCB children and it increased significantly in the ULCB group of children (Ovsenik, 2009).

The duration of the phase IIb and the entire act of swallowing was longer in the ULCB group (Figure 5). Peng et al. (2004) reported that in visceral swallwers, only the phase IIb was elongated. In the phase IIb, saliva is moving towards the pharynx, therefore the vertical movement of the tongue is minimal and the curve in the M diagram of ultrasound is almost flat. The protruded tongue in visceral swallowers probably needs more time to move from anterior...
parts of the oral cavity in the direction of the pharynx and the duration of phase IIb is therefore elongated. Ultrasonography showed that the percentage of the visceral swallowing pattern in children with ULCB was statistically significantly higher than in the non-ULCB group, which could explain the elongated phase IIb in the ULCB group. The elongated phase IIb and the entire act of swallowing could also be explained by the fact that the tongue has to complete a longer distance as the tongue in children with ULCB usually rests on the mouth floor and in the anterior part of the oral cavity, between the upper and lower incisors, which was determined by the 3D ultrasound diagnostics of tongue posture (Volk et al., 2010).

The range of tongue movements in phases I, IIa, IIb, and the entire swallowing act was significantly larger in the ULCB group. On the contrary, Peng et al. (2003) found no significant differences between the visceral and somatic swallower. In phase I, the tip of the tongue moves in the direction of the incisive papilla, consequently the middle part of the tongue becomes concave, which can be seen as a

![Figure 5](https://academic.oup.com/ejo/article-abstract/36/6/665/443441/669)

**Figure 5** Means and standard deviations of duration for each of the swallowing phases (I: shovel, IIa: early transport, IIb: late transport, IIIa: early final, and IIIb: late final phase) and for the entire swallowing act in seconds.

![Figure 6](https://academic.oup.com/ejo/article-abstract/36/6/665/443441/669)

**Figure 6** Means and standard deviations of range for each of the swallowing phases and for the entire swallowing act in millimetres.
In phase IIa, the tongue moves cranially and distally, therefore the middle part of the tongue dorsum approaches the hard palate and the concavity disappears (Peng et al., 1995). The results of our study showed greater movements of the middle of the tongue in the beginning of the swallowing cycle in the ULCB group, probably due to tongue posture on the mouth floor in children with ULCB (Volk et al., 2010). It is, however, difficult to explain the difference in the range between the groups in phase IIb, where the movements of the tongue are minimal.

The speed of tongue movements was significantly higher in phase IIb in the ULCB group (Figure 7). On the contrary, Peng et al. (2003) found significantly lower speed in visceral swallowers in phases IIa and IIIa. This may lead to the conclusion that movements of the tongue during swallowing in ULCB children are not the same as in visceral swallowers despite the very high percentage of visceral swallowers in the ULCB group.

It is very difficult to clinically assess the swallowing pattern in very small, growing children. Moreover, clinical examination of tongue movements during swallowing is very limited or impossible due to anatomical structures surrounding the tongue, and the evaluation is therefore highly subjective. Many of the methods used for more objective diagnostics of swallowing, particularly cineradiography and computer tomography, are not suitable for use in small children due to radiation. It is almost impossible to use some of sophisticated methods, for example electropalatography, electromagnetic articulography, and magnetic resonance, in growing children despite their non-invasiveness.

Simultaneous B- and M-mode ultrasonography is a non-invasive and relatively simple method and therefore enables repetitions of the diagnostic procedures. Ultrasonography makes it possible that the tongue movements during swallowing can be more objectively followed before, during, and after orthodontic treatment. The main advantage of the method is its non-invasiveness and therefore, the method is proposed to be used especially in small growing children.

2D ultrasonography was used to assess the prevalent type of swallowing in children with ULCB. The main advantage of the method is its non-invasiveness and it could therefore be used in functional diagnostics in orthodontics before, during, and after orthodontic treatment especially in small growing children. However, further follow-up studies are necessary in order to evaluate the role of the tongue function in children with ULCB on jaw morphology during growth and development.

Conclusions

1. Ultrasound analysis showed that visceral swallowing pattern is prevalent in children with ULCB.
2. Duration, range, and speed of the tongue movements during swallowing significantly differ between children with and without ULCB.
3. 2D ultrasonography is a non-invasive diagnostic method for the assessment of tongue function during swallowing and can be used especially in functional diagnostics during growth and development.
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