Acoustic properties of healthy and reconstructed cleft lip

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ABSTRACT

The feasibility of echographic imaging of the tissues in healthy lip and in reconstructed cleft lip and estimating the dimensions and the normalized echo level of these tissues is investigated. Echographic images of the upper lip were made with commercial medical ultrasound equipment, using a linear array transducer (7-11 MHz bandwidth) and a non-contact gel coupling. Tissue dimensions were measured by means of software calipers. Echo levels were calibrated and corrected for beam characteristics, gel path and tissue attenuation by using a tissue-mimicking phantom. At central position of philtrum, mean thickness (and standard deviation) of lip loose connective tissue layer, orbicularis oris muscle and dense connective layer was 4.0 (sd 0.1) mm, 2.3 (sd 0.7) mm, 2.2 (sd 0.7) mm, respectively, in healthy lip at rest. Mean (sd) echo level of muscle and dense connective tissue layer with respect to echo level of lip loose connective tissue layer was in relaxed condition: – 19.3 (sd 0.6) dB and – 10.7 (sd 4.0) dB, respectively. Echo level of loose connective tissue layer was +25.6 (sd 4.2) dB relative to phantom echo level obtained in the focus of the transducer. Color mode echo images were calculated, after adaptive filtering of the images, which show the tissues in separate colors and highlight the details of healthy lip and reconstructed cleft lip. Quantitative assessment of thickness and echo level of various lip tissues is feasible after proper calibration of the echographic equipment. Diagnostic potentials of the developed quantitative echographic techniques for non-invasive evaluation of the outcome of cleft lip reconstruction are promising.

Keywords: cleft lip, color mode, echography, healthy lip, quantitative analysis, reflectivity level, thickness

1. INTRODUCTION

Among the most significant orofacial anomalies, clefts occur most frequently, the incidence being approximately 1 in 500 to 1000 live births.¹² Cleft lip with or without cleft palate is the most common of these facial clefts. An important step in the treatment of children with cleft lip (with or without palate) is the reconstruction of the upper lip and the restoration of the continuity of the orbicularis oris muscle. Every surgical intervention, however, leads inevitably to scar formation. The amount of scar tissue and its position both have functional and esthetic consequences.⁵ Although the esthetic outcome of an intervention might be clinically judged, it remains unclear to what extent the continuity and the functionality of the muscle has been established. For this reason, it is important to investigate the anatomy of the reconstructed lip. Besides that, it is unknown to what extent scar tissue has an effect on muscle function. By making detailed anatomical information available, it might be possible to better evaluate the outcome of a treatment.

By the use of ultrasound (US) imaging, it is possible to visualize different tissues in the healthy and reconstructed upper lip.⁴⁶ Vinka-Puhakka mentioned that the orbicularis oris muscle is sandwiched between the facial and lingual connective tissues.⁵

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By comparing the US images of the upper lip in relaxed and contracted condition in both healthy and repaired cleft lip, it is possible to qualitatively relate function to anatomy. However, because of the complex healing process after reconstruction of the cleft lip it might be hard to recognize the anatomical details. To overcome this problem, image analysis was applied to conventional 2-D ultrasound images. This technique can be used after careful calibration of the ultrasound system and it enables the characterization of lip tissues by quantitative means, i.e., by the calibrated echo level.

The aim of the present study was to investigate the feasibility of differentiating the various structures in reconstructed cleft lip by qualitative and quantitative ultrasound imaging, in both relaxed and contracted condition, and to compare the results to those obtained in the healthy lip. A full paper on this subject has recently been submitted.

2. METHODS

2.1 Material
In this pilot study three young adults with normal lip anatomy and two patients with reconstructed cleft lip (one unilateral, one bilateral) and of comparable age (range: 25-35 yrs) were involved, after informed consent.

2.2 Equipment
The experiments were performed with a medical ultrasound system SONOS 7500 (Philips Medical Systems, Andover, MA, USA). A linear array transducer (11-3L) was used, which had a footprint size of (10x46) mm². The processed ultrasound pulse bandwidth was set at 7-11 MHz. Further settings of the equipment were: depth range: 20 mm; transmit focus: 11 mm; depth gain compensation (DGC): flat (zero position); lateral gain compensation (LGC): flat (mid position); transmit level MI: 1.2; overall gain: 80 dB; compression: 60 dB; post-processing curve: F.

The 2-D ultrasound images were stored at the on-board hard disk, either in JPEG format, or in DICOM format, and transferred to a PC for further processing after the examination.

2.3 Measurements
The upper lip of the subjects was prepared by extruding a one-centimeter thick layer of commercial ultrasound contact gel (Kendall Meditec, Mirandola (MO), Italy) over the full width of the upper lip for transversal scanning. Then the transducer was carefully applied to this layer while avoiding direct contact of the transducer with the lip and avoiding inclusion of air bubbles between transducer surface and gel (Fig. 1). This could be achieved in all cases, at least for the first few applications. The scheme of the tissue layers of the upper lip is shown in Fig. 2, right. The corresponding echographic image of a healthy subject is shown in Fig. 2, left.

Fig. 1. (Left) Scheme of application of ultrasound transducer on upper lip, large arrow shows the direction of the midline of the philtrum, which is the reference for the mid point of the probe; (Right) ultrasound transducer applied on lip with gel layer for transverse measurement.

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2.4 Preprocessing
Since, the echographic signals underlying the 2-D images are strongly influenced by the characteristics of the transducer, the settings and software processing of the equipment, and by the lip tissue itself (i.e., ultrasound attenuation), the overall equipment performance was carefully assessed from calibration measurements with a tissue mimicking phantom (model 550, ATS Laboratories, Bridgeport, CT, USA). The measurement protocol and the calibration procedure were described by Thijssen et al.10 This protocol enables to recode the stored digital gray levels of the images into a logarithmic scale of echo strength relative to the mean echo level of the phantom (i.e., a decibel (dB-scale), allowing quantitative analysis of the echo levels.

After this calibration of the echo processing of the equipment, the depth effects related to ultrasound beam forming, as well as to tissue attenuation, were estimated from a reference measurement in a homogeneous part of the tissue-mimicking phantom. This yielded the echo level vs. depth curve, i.e., a “calculated DGC” could be obtained which was used to compensate the lip images for the mentioned depth dependencies. Because of the curved shape of the front surface of the lip, the length of the gel path from transducer to this surface changes with position of the ultrasound path. For this reason, the attenuation is different at different lateral positions in the image. Another set of reference measurements was made with the same phantom but now with different lengths of the gel path. The resulting echo level vs. depth curves were then used to calculate the “lateral” gain compensation (LGC). After applying also this latter correction, the resulting final images can be analyzed in a quantitative manner, i.e. gray levels of different anatomical structures become available in dB vs. the mean echo level of the phantom. In addition, differences of the echo level related to different anatomical structures can be calculated in dB with respect to each other unambiguously.

2.5 Processing
The thickness of the various tissues of the upper lip was measured in the transversal images at three positions: mid philtrum and left and right of philtrum (small vertical arrows in Fig. 3). The thicknesses were measured interactively, off-line, by using the depth markers in the stored images as a calibration. The layers measured were the sub-epidermal loose connective tissue, the orbicularis oris muscle and the sub-muscular dense connective tissue layer. In general, the distal lip mucosa layer was easily identified just proximal to the black echo zone corresponding to the saliva layer between lip and gum. The echo level of the various layers was measured in the preprocessed images by using the software for off-line analysis. The mouse

Fig. 2. (Above) Scheme of upper lip layers in transversal image; (below) transversal image of healthy subject

Fig. 3. Scheme of the transversal image cross section with arrows at positions of layers thickness measurements.
A link was programmed to select interactively a certain region (Fig. 4, Left) and the histogram of gray levels in that region was displayed (Fig. 4, Right). This histogram was characterized by two parameters: mean and standard deviation. The echographic images were further processed by an adaptive mean squares filter to improve the distinction between the various layers in the upper lip. After this step, the gray levels were converted to a color scale in order to highlight the presence of scar tissue in the images of the two patients involved in this study.

3. RESULTS

Images of high quality were obtained by the gel layer application method and using the linear array transducer at the highest achievable bandwidth (7-11 MHz). Thickness of the various tissue layers of the lip becomes gradually less from the center to the most lateral area of the lip. The results of the thickness measurements of three healthy subjects are given in Table I. It appears that the lip loose connective tissue layer is the thickest layer: from 4.0 mm (center) to 5.9 mm (largest value) in relaxed condition. The orbicularis oris muscle and the dense connective tissue layer are of comparable thickness, but 60% thinner than the loose connective tissue layer. Data obtained at central position are displaying a relatively large spread because of anatomical peculiarity in one of the three subjects, i.e., a circular extension of the muscle into the loose connective tissue layer.

Relative echo level (or: reflectivity level, image gray level, etc.) of the various tissues in relaxed condition is given in Table II. The echo level in the muscle layer was –19.3 (sd 4.2) dB lower than in the lip loose connective tissue and –10.7 (sd 4.0) dB higher than in the dense connective tissue layer.

<table>
<thead>
<tr>
<th>tissue position</th>
<th>Loose connective tissue layer</th>
<th>Muscle</th>
<th>Dense connective tissue layer</th>
<th>Total lip</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
<td>Mean</td>
<td>SD</td>
</tr>
<tr>
<td>central</td>
<td>4.0</td>
<td>0.1</td>
<td>2.3</td>
<td>0.7</td>
</tr>
<tr>
<td>right</td>
<td>5.9</td>
<td>1.2</td>
<td>1.8</td>
<td>0.3</td>
</tr>
<tr>
<td>left</td>
<td>5.9</td>
<td>1.0</td>
<td>1.8</td>
<td>0.0</td>
</tr>
</tbody>
</table>

Fig. 4. (Left) Transversal calibrated B-mode image with drawn regions-of-interest to be characterized; (Right) histogram of gray levels (dB) in loose connective tissue layer, muscle and dense connective tissue layer.
TABLE II. Relative echo level of the lip tissue layers, expressed in dB with respect to phantom echo level, and difference between levels of the various layers (dB). Mean and standard deviation of data in three healthy subjects

<table>
<thead>
<tr>
<th>Structure</th>
<th>Loose connective tissue</th>
<th>Muscle</th>
<th>Dense connective tissue</th>
<th>Muscle-loose connective tissue</th>
<th>(loose-dense) connective tissue</th>
<th>Muscle-dense connective tissue</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean (dB)</td>
<td>25.6</td>
<td>6.3</td>
<td>17.0</td>
<td>-19.3</td>
<td>8.7</td>
<td>-10.7</td>
</tr>
<tr>
<td>SD (dB)</td>
<td>4.2</td>
<td>4.6</td>
<td>8.1</td>
<td>0.6</td>
<td>4.2</td>
<td>4.0</td>
</tr>
</tbody>
</table>

The calibrated B-mode image echo levels were segmented into three classes and then displayed in three-color mode as is shown next to the B-mode image for a normal subject in Fig. 5. It appears that the color zones follow the anatomical outlines of the tissue layers fairly well. For comparison, the same images obtained in a reconstructed bi-lateral cleft lip are shown in Fig. 6. Although many reconstruction-related details are visible already in the calibrated B-mode image, some more pregnant outlining becomes evident due to the color-coding.

4. DISCUSSION

This study shows that with the use of ultrasound imaging the various anatomical structures of the upper lip could easily be identified and distinguished. Although the feasibility of imaging lip structures was shown by other authors, the present paper is adding new, quantitative information about the lip tissues.

This study is meant to be a feasibility study for the use of echographic imaging in the assessment of cleft lip reconstructive surgery and should be considered as limited as such. So, the conclusions about absolute values of the thickness of the various layers of the lip are indicating an order of magnitude only.

The muscle thickness results of Table I may be compared to those obtained by Prabhu and Munshi. These authors found in rest (n=17) a mean value in the center of the lip of 4.4 (sd 1.2) mm. It is observed that the mean thickness in the present study is about half the value found by these authors. In a subsequent study, Rasheed and Munshi observed a central muscle thickness in healthy subjects (n=10) of 5.6 (sd 0.5) mm at rest. Again this value are approximately two times those found in the present study. It is not evident how to explain this big difference from a technological point of view, because in general the manufacturer calibrates medical ultrasound equipment at a speed of sound of 1540 m/s. The observed differences might be caused by a different definition of the muscle boundaries, or by anatomical differences related to race.

Fig. 5. (Left) Example of calibrated transversal B-mode image of healthy subject; (Right) color coded image.
The present results (Table I) are, however, in close agreement with those obtained by Vinkka-Puhakka et al., who found for (n=11) e.g., a central overall upper lip thickness of 7.1 (sd 0.8) mm, whereas, the central muscle thickness was 1.2 (sd 0.5) mm.5

No data can be found in literature on the quantitative aspects of echographic images of the upper lip. From all the papers on lip echography, it becomes evident that the muscles are visualized as relatively hypo-echoic zones in between more reflective layers of connective tissue. In this paper it is found that muscles are producing echo (amplitude) levels which are approximately 19 dB lower than those of the proximal loose connective tissue layer, which corresponds to a factor of 9 times less reflectiveness and 10 dB less than those of the dense connective tissue layer, which is equivalent to 3 times less.

Scar tissue is tissue with a low density of cells and blood vessels and a more parallel ranking of collagen. Areas that contain scar tissue may be revealed by lower echo level (hypo echoic, dark zones) within a healthy tissue layer, or as an area with a higher echo-level (hyper echoic, bright zones) as well (Fig. 6, above). The echo level is dependent, among others, on the angle of incidence of the ultrasound with respect to the proximal surface of the scar.

The importance of the results of these new methods is that objective information about the state of the reconstructed cleft lip becomes available prior to revision surgery. Moreover, the quantitative information of lip tissues might be used in future comparative studies of different surgical techniques and in different clinical centers. Until now available methods were restricted to visual clinical examination of the patient, which does not allow for any anatomical details about the scar and the orbicularis oris muscle, nor of its function.

The information gained from the present study is contributing to the introduction of an emerging ultrasound technique, which is called “elastography”, for studying the lip. Elastography is a quantitative and qualitative technique to map tissue deformation after e.g., external compression, or muscle contraction. The deformation can be related to the elasticity of tissues.14,15 Elastography has never been described in studies about the lip, except in a recent conference proceedings publication by the present authors.16

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