Ultrasonographic Evaluation of Calcification Patterns in Costal Cartilage: Implications for Rib Graft Harvesting

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Importance
Complex augmentation rhinoplasty often requires the use of cartilaginous grafts, especially in revision surgery. When using costal cartilage, the possibility of inadequate cartilage material because of excessive calcification must always be kept in mind. Furthermore, cartilage may be harvested but found to be not ideal, causing unsatisfying results.

Objective
To report our experience with the use of preoperative ultrasonographic (US) examinations for quality analysis of costal cartilage.

Design, Setting, and Participants
In an academic research setting, US imaging of the anterior rib cage was performed before 83 revision rhinoplasties requiring costal cartilage grafting.

Main Outcomes and Measures
Cartilage volume, quality, sex-specific calcification patterns, and the location of hidden calcification islands within viable cartilage were recorded.

Results
Two different calcification patterns, 1 central and 1 peripheral, were identified.

Conclusions and Relevance
We found this cost-effective technique to be a valuable tool for easy preoperative cartilage assessment. Furthermore, US screening guides the surgeon to areas of harvestable cartilage and to cartilage that is best suited for rhinoplasty in terms of distribution patterns of calcification areas.

Level of Evidence
NA.

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Autogenous costal cartilage grafts have gained widespread use in revision rhinoplasty. Especially in patients with major cartilaginous tissue needs, rib cartilage is considered the gold standard by many. It provides greater amounts of cartilage in cases in which conchal or septal cartilage leave limited material. Costal cartilage may be carved into various shapes, and it retains this shape over time. However, there are some major associated disadvantages, namely, unforeseen cartilage warping and potentially high morbidity of the harvesting procedure. As far as the warping problem is concerned, rib cartilage serves well for nasal implants as long as the principles of balanced cross-section carving, as established by Gibson and Davis,1 are respected. The morbidity associated with the harvesting procedure mandates a successful harvest. Abandoned harvesting procedures because of inadequate cartilage with excessive calcification are frustrating to the patient and surgeon. The fear of progressive cartilage calcification has influenced some surgeons in their choice of possible donor sites, resulting in age limits for costal harvesting.2-5 We have experienced several abandoned harvesting procedures because of excessive calcification and initiated this study to investigate the ossification patterns of rib cartilage. In this article, sonographic, macroscopic, and microscopic aspects of costal ossification are described. Age and sex correlations are presented, and a preoperative examination is introduced that has become clinically routine before every revision rhinoplasty in our departments.

Current knowledge on the pattern and extent of costal cartilage osteogenesis originates mainly from research performed by forensic scientists using chest wall radiographs and ultrasonographic (US) examinations.6-9 Ossification patterns of the costal cartilage are used as indicators of age and sex in forensic science. Rejtarová et al10 and other investigators10-11 proved that age and sex correlate with different patterns of costal cartilage calcification.
Figure 1. Ultrasonographic Examination

A, Panoramic (SieScape; Siemens Medical, Inc) cross-sectional image of the sixth and eighth ribs. The numerals indicate the sixth, seventh, eighth, and ninth ribs. B, Cartilage of the sixth rib of an 18-year-old male shows homogeneous cartilage with a diameter of 6.5 × 0.7 cm at the costochondral junction between the bone and cartilage and the chondrosternal junction between the cartilage and sternum. C, Cross-section at the sternocostal joint. D, Cross-section at a previous cartilage-harvesting spot. BONE indicates costal bone, CART, cartilage, L, lung; OSS, sternal bone; R, rib cartilage, SCAR, scar tissue; and ST, sternum.

Results

US Examination and Histological Findings
The US examination was performed before the operation, either the day before or just before surgery. All US examinations produced suitable results. Images were stored on the local hard drive, and the location of adequate cartilaginous material was outlined on the patient's skin. The cartilaginous rib was visible as a hypoechogenic band (Figure 1B) and was confined on both bony junctures by hyperechogenic lines with distal signal attenuation (Figure 1C). Histological workup on the rib specimen confirmed calcification islands in corresponding areas that were highlighted and indicated by the US examination (Figure 2 and Figure 3). Ossification and calcification islands had a sonographic picture of hyperechogenic structures within (central calcification pattern) or on the surface of (peripheral calcification pattern) the cartilaginous rib. Depending on the calcification and ossification process, distal signal attenuation was observed (Figure 4).

Patient Findings
By applying the US technique, we observed calcification patterns in 100% of 74 patients enrolled in this study. All pa-
patients had signs of calcification islands. Two types of calcification patterns were differentiated according to US images. A central pattern was observed in 55% (41 of 74) of male patients and in 60% (44 of 74) of female patients. A peripheral pattern was observed in 45% (33 of 74) of male patients and in 39% (29 of 74) of female patients (Table). These data were not statistically significant but showed a trend toward a central pattern for women and a peripheral pattern among men. No cases were observed in which a random or mixed pattern of central and peripheral patterns occurred side by side.

Furthermore, no correlation between age and calcification pattern was evident in this study group. We obtained cartilage material in all patients, irrespective of age. However, the cartilaginous parts seemed shorter with increasing age.

**Surgical Procedure**

All patients with a preoperative US examination had a successful cartilage-harvesting procedure. No procedures were aborted because of excessive calcification. In areas with large peripheral calcification islands, we selected a different rib for harvesting and always found a suitable location with minor or less calcification.

Usually, we obtained the fifth rib. In cases with signs of extensive ossification, we switched to the fourth or sixth rib. After we started performing US examinations on all patients, two-thirds of cases used the fourth or sixth rib instead of the fifth rib. No switching of sides was necessary. The duration of the US examination, including setup and completion, was 4 minutes. Fast US examinations were preformed in under 1 minute. In cases with excessive calcification and an extensive search for viable cartilage, the maximum time for an US examination was 8 minutes. The examination is preformed by otolaryngologists, and the range of duration is 5 to 10 minutes. It can be performed after short training by inexperienced persons without in-depth knowledge of sonographic technologies.

**Discussion**

Autogenous costal cartilage is easily acquired in large quantities. However, its acquisition is accompanied by certain risks and undesirable comorbidities, such as pneumothorax, deformities of the costal arches, and postoperative pain and infections, as well as visible scarring. These factors mandate a successful harvesting procedure. An aborted procedure because of excessive ossification is an unpleasant situation. After experiencing a case in which we found insufficient viable...
cartilage material because of unforeseen excessive ossification, we decided to investigate the benefit of preoperative US examinations of the costal arches. US examination was described by Tasman and Helbig12 in the context of rhinoplasty, with successful assessment of the nasal tip configuration. Our goal was to identify the best possible cartilage for our operation by applying this fast, harmless technique and ubiquitous hardware.

In all patients who underwent costal cartilage harvesting, we performed US examination of the costal arches and found viable cartilage material. By screening the cartilaginous areas, we observed a notable dissemination of calcification islands. These calcification islands are considered the origin of natural cartilage ossification. Rejtarová et al6 and other investigators7-9 showed that the formation of ossification is distributed some surgeons to limit harvesting of rib cartilage in patients older than 40 years. By screening the entire costal arches, we always found viable cartilage, regardless of the patient’s age, so we do not limit cartilage harvesting to a certain age group. Therefore, US imaging is valuable to direct the surgeon to areas with harvestable cartilage.

A reason why costal cartilage can be a troublesome material is its dissimilarity in consistency, with unpredictable amounts of absorption and the tendency to buckle. We found cartilage with a central calcification pattern to be favorable for warping. When we used the core of the rib with its calcification islands for graft carving, we observed practically no immediate or delayed warping. Of course, the material is considerably more fragile because of the crumbly calcification islands but was usable in our hands. Therefore, we changed our protocol to specifically search for cartilage areas with an evenly distributed longitudinal central calcification pattern. Cartilage with a large peripheral calcification pattern has been less favorable for graft carving in our hands. When we remove the outer calcification areas, our experience is that the cartilage immediately starts warping, despite the use of balanced cross-section carving, as postulated by Gibson and Davis.1

We conclude that our US technique is useful in predicting cartilage quality before harvesting procedures. We found that age and sex alone are not significant criteria to predict cartilage quality. Our motivation for performing preoperative US examinations has evolved from the question of whether suitable cartilage can be found to a certainty about where to find the ideal cartilage material. Therefore, we perform US examinations in every patient undergoing revision rhinoplasty.

Table. Calcification Patterns in Rib Cartilage Assessed by Ultrasonographic Examination in 74 Patients Undergoing Revision Rhinoplasty

<table>
<thead>
<tr>
<th>Calcification Pattern</th>
<th>Male (n = 46)</th>
<th>Female (n = 37)</th>
<th>Age, y</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>≤40</td>
</tr>
<tr>
<td>Peripheral</td>
<td>33 (45)</td>
<td>29 (39)</td>
<td>44</td>
</tr>
<tr>
<td>Central</td>
<td>41 (55)</td>
<td>44 (60)</td>
<td>51</td>
</tr>
<tr>
<td>None</td>
<td>0</td>
<td>1 (1)</td>
<td>1</td>
</tr>
</tbody>
</table>

* Data are given as a number (percentage) except for age, which for clarity is given as a percentage only.