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THE COSTAL ARCH CARTILAGE EVALUATION BY RADIOLOGISTS BEFORE RECONSTRUCTION SURGERIES

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INTRODUCTION

Costal arch cartilage is used by many surgeons as a substrate source for reconstruction of other chondral structures in the human body, such as the auricle, the thyroid cartilage or the nose. Preoperative evaluation of the costal arch cartilage is necessary, since the presence of small amounts of chondral calcifications can interfere with the postoperative outcomes. In this sense, the radiologist may be able to perform this evaluation informing, for example, if the patient has an adequate supply of costal arch cartilage available for the surgery, with the least amount of calcification as possible, and pointing where is the best place to perform the harvesting, taking into account the peculiarities of the surgery itself.

ANATOMY OF THE COSTAL CARTILAGE

The rib cage(Figure 1)is a semirigid but expansible cage that surrounds the lungs and the heart, providing bone protection for these vital organs and consists of twelvepairs of ribs that articulates dorsally to the thoracic column and ventrally to the sternum. The costal arch (rib) is a flat curved bone and its flexibility allows the lungs to expand, facilitating breathing; the most common anatomic variations are the cervical rib, bifid rib and short (hypoplastic) rib.

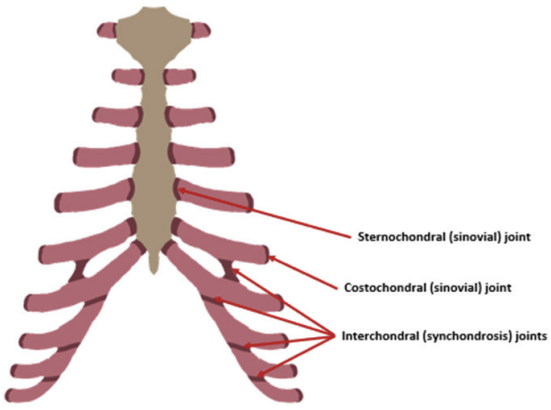


Figure 1 – The costal cartilage

True ribs (1-7) articulate directly to the sternum by its own costal cartilage, false ribs (8-10) articulate indirectly to the sternum through the adjacent superior costal cartilage and floating ribs (11 and 12) do not connect to the sternum at all.

Costal arch cartilages are segments of hyaline cartilage, rich in water and collagen, found in most bones' articular surfaces. The articular cartilage is unprovided of neurovascular supply and it is a specialized type of hyaline cartilage, that differs from the others in the distribution of the chondrocytes and collagen fibers. Its flexibility allows the costal arches to move forward and laterally, increasing anteroposterior and lateral diameter of the thoracic cavity, facilitating breathing. This "bucket handle movement" of the thorax allows the ribs to move outward, increasing thoracic transverse diameter.

The intercostal space (Figure 2) is the anatomic place between two costal arches, numbered according to the costal arch above, adding up to eleven intercostal spaces each side. They contain three layers of muscles (external, internal and innermost), and neurovascular bundles (internal thoracic and collateral, located between internal and innermost muscles).

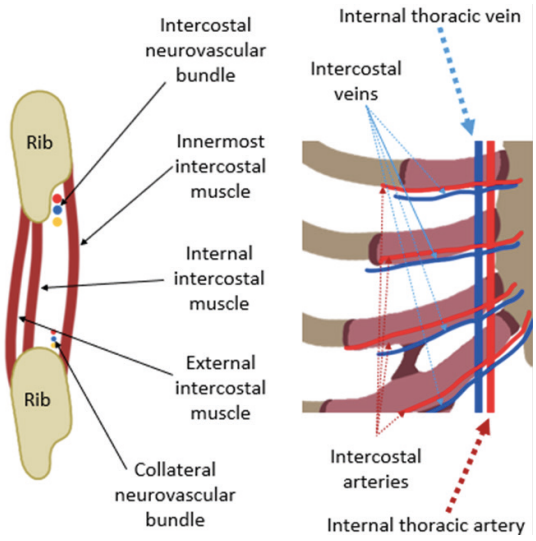


Figure 2 – The intercostal space

Their arterial supply comes from one posterior and two anterior intercostal arteries; intercostal veins drain the anterior intercostal space to the internal thoracic vein and the posterior intercostal space to the azygos/ hemiazygos veins.

Innervation arises from anterior rami of spinal nerves T1-T11, for both motor and sensory purposes.

Focusing now in the cartilage, there are three types in human body: the fibrocartilage, that is found in knee meniscus, intervertebral discs and insertion of tendons, made of thick layers of collagen, giving it a high tensile strength; the elastic cartilage, that is found in external ear, larynx and epiglottis, which contains abundant elastic fibers so the tissue can resist to repetitive deformation stress; and the hyaline cartilage found in joints, physeal, costal and nasal cartilages.

In the hyaline cartilage (figure 3) their superficial zone has chondrocytes that are flattened and collagen fibers that are aligned parallel to the articular surface, protecting the deeper layers from tensile forces; in the deep zone the collagen fibers are perpendicular arranged to the articular surface, giving it resistant to compressive forces.

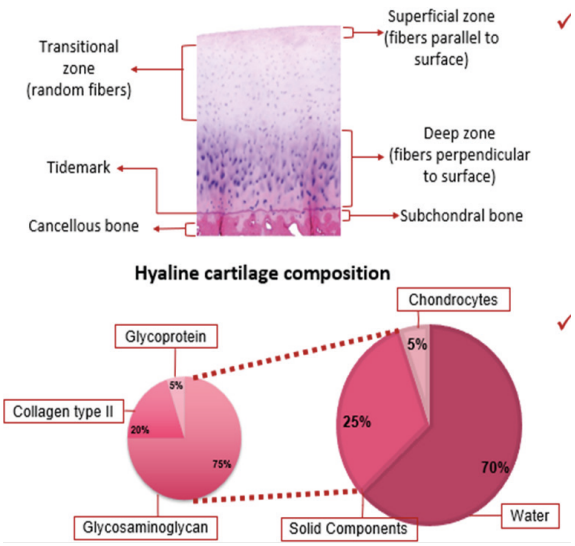


Figure 3 – Features of the hyaline cartilage

COSTAL ARCH CARTILAGE AND RECONSTRUCTIVE SURGERIES

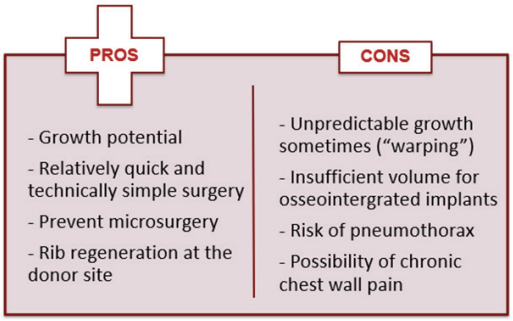


Figure 4 – Pros and cons of costal arch cartilage use in reconstructive surgeries

As cartilages are difficult to regenerate in mature skeletons, the repair of osteochondral lesions has started using initially hyaline cartilage grafts as surgical implants, with its advantages and disadvantages for its use (Figure 4).

Since then, the surgical use of this type of cartilage has been refined, due to its flexibility, malleability and resistance, mainly in the replacement of injured cartilaginous structures, such as the nose and the auricle.

The first documented autograft cartilage use in rhinoplasty was made by James Israel in 1896, seeking to overcome the organic rejection of platinum or ivory prosthesis. He used a tibial bone graft. Nowadays, the most required donor site of autologous cartilage grafts for rhinoplasty is the nasal septum, followed by the costal arches. And even in immature skeletons, where there are many cartilage graft donation sites available, the best of them are still the costal arches.

COSTAL ARCH CARTILAGE CALCIFICATIONS

The endochondral ossification process is driven by the increase of extracellular chondral matrix vesicles (ECMVs) with stimulating calcification factors, and leading to more calcium binding sites exposure on the extracellular membrane glycoproteins. Osteoblasts replaces chondrocytes, forming ossification center, and bone tissue grows based in a chondral scaffold.

The abnormal process of calcium deposition in cartilage starts with aging or conditions of altered calcium metabolism, leading to excessive calcium levels in the serum and in extracellular compartments. Chondral calcification stimulating factors also are implied in this process, exposing calcium binding on extracellular membrane proteins predisposed sites, and leading to chondrocalcinosis.

Calcifications in costal arch cartilages hinder their use as autografts on reconstructive surgery, once calcified cartilages are more rigid, and therefore more difficult to extract from the costal arches ("harvesting"), increasing the risk of pneumothorax, for instance.

This stiffness also makes it difficult for the surgeon to manipulate cartilage for the graft framing. These grafts with calcified cartilage also have an increased chance of irregular absorption.

IMAGING EVALUATION OF COSTAL ARCH CARTILAGE CALCIFICATIONS

Cartilage of the costal arch can present calcifications on its external surface and in its inner matrix, on diverse quantities and extensions.

Prior the surgery, in the past, the costal arch cartilage was "pricked" to evaluate chondral stiffness due to calcifications, but after they became easily detected by radiography (RX, figure 6), computed tomography scan (CT, figure 7) and ultrasound (US, figure 8), and even by magnetic resonance imaging (MRI, figure 9).

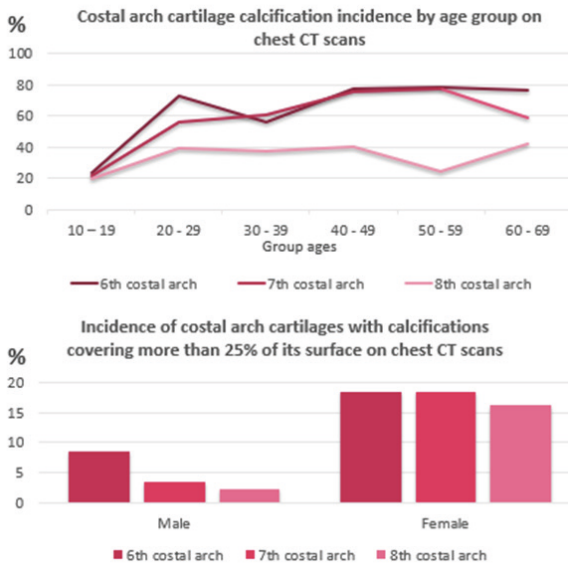


Figure 5 – Incidence of costal arch cartilage calcifications by age and genre in Chest CT scans *(Sunwoo et al, 2014)*

Imaging methods are also important to identify the best location for cartilage harvesting, which is at the costochondral junction of the sixth, seventh and eighth ribs, usually on the patient's right side, as they are safer and more accessible.

Likewise, it is needed to identify other cartilage donor site, when calcifications cover more than 25% of the chondral surface, or if they exhibit a central or a granular pattern morphology, once this kind of cartilage is inadequate as autograft.

Sunwoo et al (figure 5) reported not only the increase of calcifications at the costal arch cartilage with aging, but also demonstrated that this process tends to be more prevalent in females, starting around 30 years old, in Asian population.

HOW TO REPORT COSTAL ARCH CARTILAGE CALCIFICATIONS IN CT SCANS

What the radiologist can highlight in his report for the evaluation of the calcifications in cartilages of the costal arches, on the preoperative period of reconstructive surgeries? Above, there is a suggestion of CT scan report sample to specifically study those calcifications for pre-surgical purposes (Figure 10). First it is required to cite the presence or absence of cartilage calcifications at the collection sites, as indicated by the surgeon (generally the sixth, seventh or eighth costal arches). In the presence of calcifications, then describe in which costal arches they are, which is its morphology, (central or peripheral), what is its extension and an estimative of its involvement percentage (%). Next, identify alternative topographies (other costal arches), to carry out the collection in case of calcifications that extends more than 50% of the costal arch surface, or with a central morphology distribution.

COMPUTED TOMOGRAPHY OF THE COSTAL ARCH CARTILAGES
INDICATION ex.: preoperative for nose reconstruction surgery
TECHNIQUE
REPORT: **1 - SIDE:** right, left **2 - WHICH ARCHES:** sixth, seventh... **3 - PRESENCE OF CALCIFICATIONS:** yes, no **4 - LOCATION AND DISTRIBUTION:** lateral, central or medial portion of the costal arch; central or peripheral. **5 - PERCENTAGE OF INVOLVEMENT:** 25%... **6- OTHER FINDINGS:** patient-relevant findings of the other structures included in the acquisition.
OPINION:

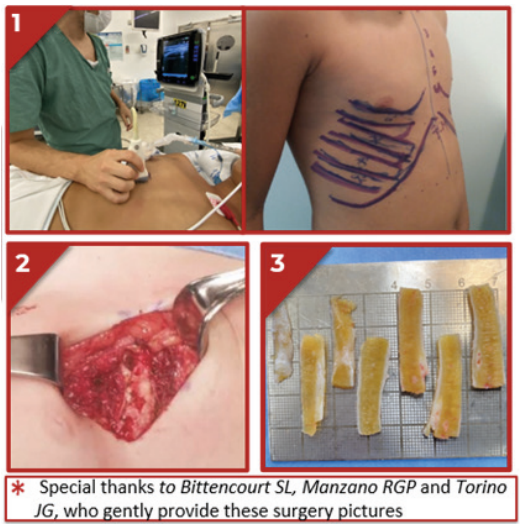
Figure 10 –Costal Arch Cartilage CT Scan's report suggestion

COSTAL ARCH CARTILAGE SURGERY

The harvesting technique of the costal arch cartilage (Figure 11) starts by finding the right costal arch with a skin mark for guidance, followed by the harvesting incision, exposure and release, and the carving and designing of the graft as needed.

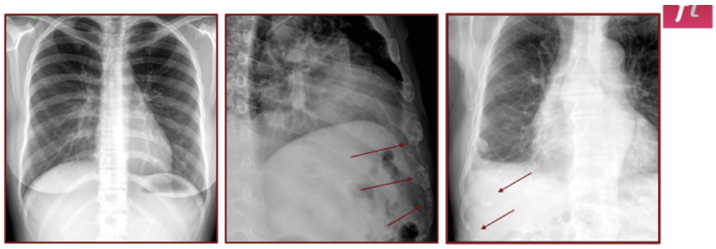
The pre-operative depends on the type of the cartilage graft (cartilage-only or osseocartilaginous), preferring the right side, once the left-sided harvesting can lead to inadvertent entry into the pericardial space, and postoperative pain may mimic cardiac pain. Gender is also considered, once the surgical incision has to be done in the mammary crease in women, with caution if there are breast implants.

As potential complications, can be highlighted pneumothorax, hemorrhage, infection, intercostal nerve injury, post-operative chest wall, and deformity. The costal arch harvesting is not indicated for patient less than one-year old, in older age groups, in patients with osteogenesis imperfecta, in the presence of extensive or diffuse cartilaginous ossifications, if there is restrictive lung disease historic, and in recent pulmonary infection.



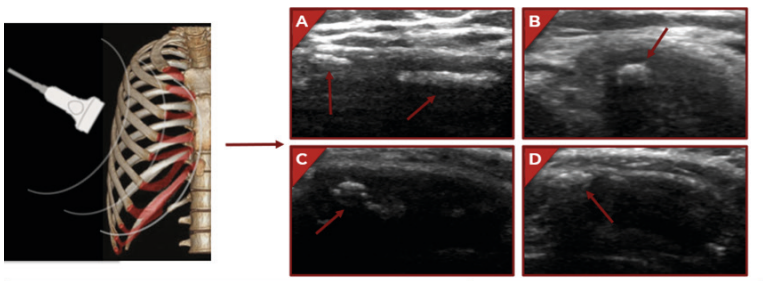
* Special thanks *to Bittencourt SL, Manzano RGP* and *Torino JG*, who gently provide these surgery pictures

Figure 11 – Costal arch harvesting technique



The evaluation of costal arch calcifications by radiography, although less sensitive, can exhibits small amounts of chondral calcifications, even if incidentally, for example, in abdominal radiographs. Therefore, although the measurement of calcium is not accurate, as it is for example on the CT scan, it can serve to contraindicate the rib harvesting, when there is extensive calcifications, or to indicate the best laterality and costal arch to be harvested.

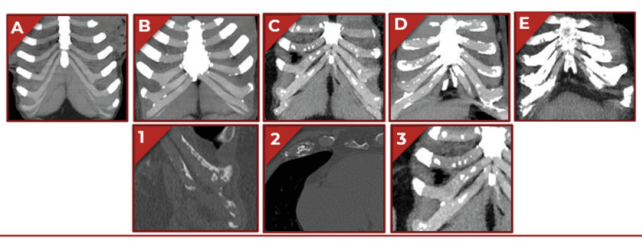
Figure 6 –Radiography evaluation of costal arch cartilage



The ultrasound assessment of costal arch cartilages has the differential of being dynamic and versatile, as can be performed even immediately before surgery in the operating facility room. Thus, it can detect intrachondral calcification foci, which are harder to detect in comparison to peripheral chondral calcifications.

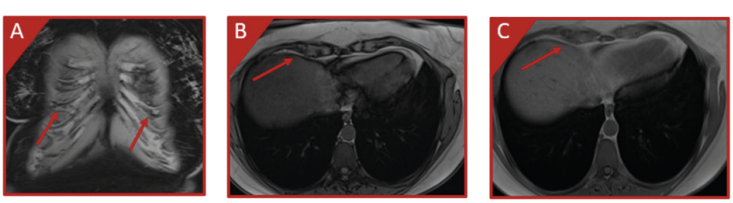
Ultrasound technique to evaluate calcifications of the costal arches (prioritizing the evaluation of the lowest ribs):
A & C) evaluation on sagittal plane
B & D) evaluation on axial plane

Figure 7 – Ultrasound evaluation of costal arch cartilage



CT scan has high sensitivity in the evaluation of costal arches calcifications, showing the extent and morphology of calcifications. *Sunwood et al* proposed a method for classifying these calcifications by CT:
- **Percentage of costal arch calcifications extension: A) 0% B) 1-25% C) 26-50% D) 51-75% E) 76-100%**
- **Morphology of costal arch calcifications: 1) Marginal 2) Granular 3) Central**

Figure 8 – Computed Tomography evaluation of costal arch cartilage



Axial nonenhanced fat-suppressed T1-weighted MR image exhibits calcifications in costal arches as hypointense foci (arrows). Axial T1-weighted GRE images displays the decrease of signal in costal arches calcifications in the opposed-phase image (B), compared with in-phase image (C) (arrows).

Although magnetic resonance imaging is not the method of choice to evaluate the costal arch cartilage, some sequences can highlight with relative sensitivity the calcifications present on it, as shown above. Therefore, the best acquisitions to visualize calcifications are those that determine the best contrast between cartilage and calcifications, such as T1-weighted GRE or fat-suppressed ones.

Figure 9 –Magnetic Resonance evaluation of costal arch cartilage

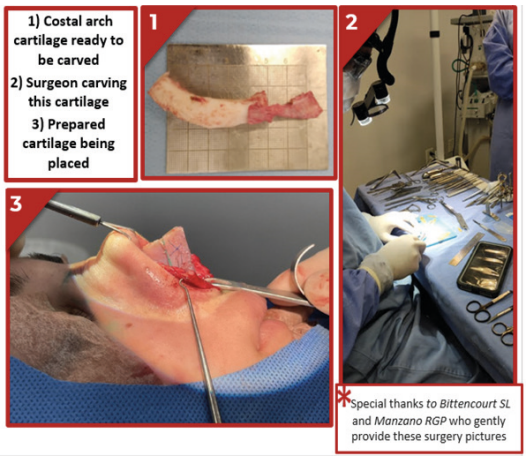


Figure 12 – Costal arch cartilage use in rhinoplasty

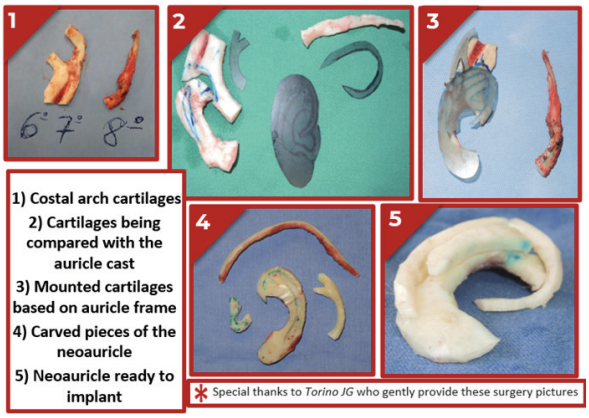


Figure 13 – Costal arch cartilage use in otoplasty

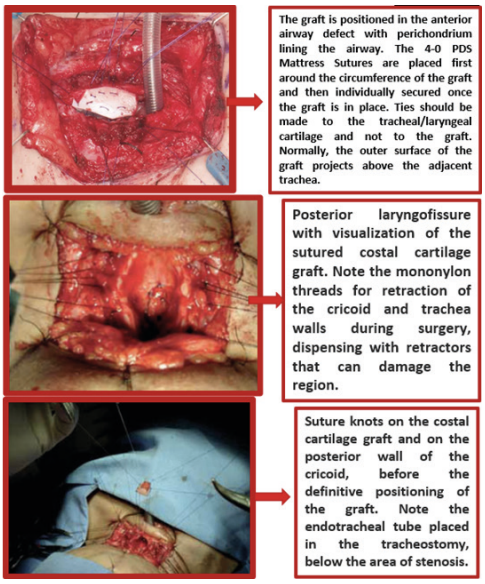


Figure 14 –Costal arch cartilage use in laryngotracheal reconstruction

Regarding the rhinoplasty surgery (Figure 12), in comparison to synthetic implants, the autogenous cartilage graft from costal arches is better because has lesser possibility of infection and extrusion. But it has a possibility of a postoperative nose "warping" as side effect. Costal arch cartilage has great value for rhinoplasty and its use is a well-established technique amongst rhinoplasty surgeons, being indicated for correction of saddle nose deformities, nasal tip underprojection and revision rhinoplasties.

Otoplasty may be necessary when the patient is born with some auricle deformity or when the ear undergoes some type of trauma that alters its original formation, which requires complex surgery techniques using autogenous costal cartilage.

Costal arch cartilage is specially used for microtia reconstruction (Figure 13), where is used for auricle augmentation. Microtia should not be operated before seven years old, because before that period, it is not assured that ear will have reached its final size, and also the thorax development may not be sufficient to allow remove enough amount of donor cartilage.

The main indication of laryngotracheal reconstruction (Figure 14) is to provide a stable airway without aid of a cannula, so in this sense, the laryngotracheoplasty (surgery to increase the diameter of the airway through cartilage grafts) can be performed.

This is indicated in cases of congenital and mainly acquired subglottic strictures – strictures after prolonged intubation, burnings caused by smoke aspiration, ingestion of caustics, surgery and radiotherapy; chronic granulomatous infections and others. The laryngotracheal reconstructive surgery

with costal cartilage and bone appears to in neoplastic diseases.

In these cases, the costal arch cartilage not only contributes in functional recovery, but also in an aesthetic wise.

The use of different costal components as grafts is established in head and neck reconstruction surgeries (Figure 15) for different causes, such as post-traumatic injuries, as temporomandibular joint ankylosis, and as secondary reconstructions in neoplastic diseases.

In these cases, the costal arch cartilage not only contributes in functional recovery, but also in an aesthetic wise.

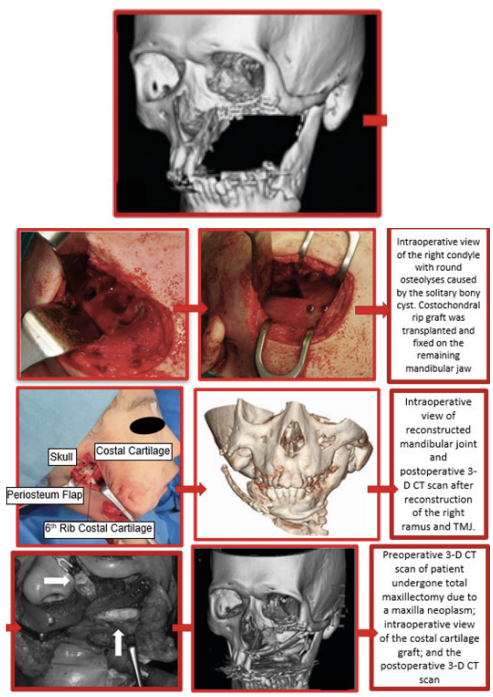


Figure 15 – Costal arch cartilage use in facial reconstruction

CONCLUSION

Costal arch cartilage is used due to its flexibility, malleability and resistance. The calcified cartilages are unwanted because they are more rigid, and therefore more difficult to extract from the costal arches ("harvesting"). This rigidity also makes it difficult for the surgeon to manipulate the cartilage and it also have an increased chance of irregular absorption.

The radiologist must be attentive and report ribs that have an extension of calcification above 25% and, thus, contraindicate the use of a rib. Cartilages with calcifications of granular or marginal morphology should also not be used. CT scan is the highest sensitivity method in the evaluation of costal arches calcifications, showing the extent and morphology of calcifications.

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