Knee Surg Sports Traumatol Arthrosc
DOI 10.1007/s00167-013-2391-5

SHOULDER

Normal curvature of glenoid surface can be restored when performing an inlay osteochondral allograft: an anatomic computed tomographic comparison

Daniel Rios · Kyle S. Jansson · Frank Martetschläger · Robert E. Boykin · Peter J. Millett · Coen A. Wijdicks

Received: 18 September 2012 / Accepted: 7 January 2013

Abstract
Purpose The purpose of this study was to quantitatively measure the morphology of the glenoid and to assess feasibility of using the medial tibial plateau surface as a donor for osteoarticular allograft reconstruction of the glenoid.
Methods Using computed tomography (CT), 10 tibias and 10 scapular models from our database (5 males and 5 females in each group) were randomly selected. Commercial software (Mimics, Materialize, Inc., Plymouth, MI) was used to extract the bone contours from the CT images and to reconstruct the 3-dimensional (3D) geometry of the scapula and tibia. By utilizing the software Creo Elements/Pro 5.0 (Parametric Technology Corp., Needham, MA), mean length and width of both the glenoid and medial tibial plateau were calculated. Radius of curvature was then measured in each 3D CT model at three intermediate segment points that were established within the length line at 25, 50, and 75 percent from superior to inferior in the glenoid and from posterior to anterior in the medial tibial plateau. Statistical analysis was performed and determined to be significant for $P < 0.05$.
Results The mean (±SD) radius of curvature values at the established 25, 50, and 75 percent segments of the glenoid were 47.4 ± 17.5 mm, 51.2 ± 12.4 mm, and 45.9 ± 17.0 mm, respectively. For the medial tibial plateau, the radius of curvature at 25, 50, and 75 percent were 43.5 ± 9.7 mm, 37.4 ± 14.3 mm and 52.3 ± 21.5 mm, respectively. Values of the glenoid length were 34.0 ± 2.9 mm, and width values were 24.4 ± 2.3 mm. For the medial tibial plateau, the length was 42.6 ± 2.7 mm, and the width was 23.3 ± 4.3 mm. There was no statistical difference in the radius of curvature and dimensional surface area between the glenoid and medial tibial plateau surfaces.
Conclusion The 3D CT-based anatomic study found that there is a statistically similar relationship in the radius of curvature of the glenoid and the medial tibial plateau surface. This concept may allow the medial tibial plateau to be used as a donor for osteoarticular allograft reconstruction of the glenoid, especially in young patients where previous studies have demonstrated that the success rate in shoulder replacements is not as good as in older patients.

Keywords Osteochondral allograft · Glenoid · Medial tibial plateau · Radius of curvature · Articular surface · Donor site

D. Rios · K. S. Jansson · F. Martetschläger · R. E. Boykin · P. J. Millett · C. A. Wijdicks (✉)
Department of BioMedical Engineering, Steadman Philippon Research Institute (SPRI), 181 W. Meadow Drive, Suite 1000, Vail, CO 81657, USA
e-mail: cwijdicks@sprivail.org

P. J. Millett
The Steadman Clinic, Vail, CO, USA

Introduction

Various techniques for cartilage repair and resurfacing have been described in the literature for many different joints [2, 3, 6]. The use of osteochondral allografts has shown to be one of the best options that can restore mature hyaline cartilage in a biological and structurally appropriate manner [2, 6]. Success can be attributed to research dedicated to improved harvesting, storage, and chondrocyte preservation in addition to transplantation techniques [6]. While these grafts are commonly used in the knee, there is a paucity of data regarding grafting of the shoulder.

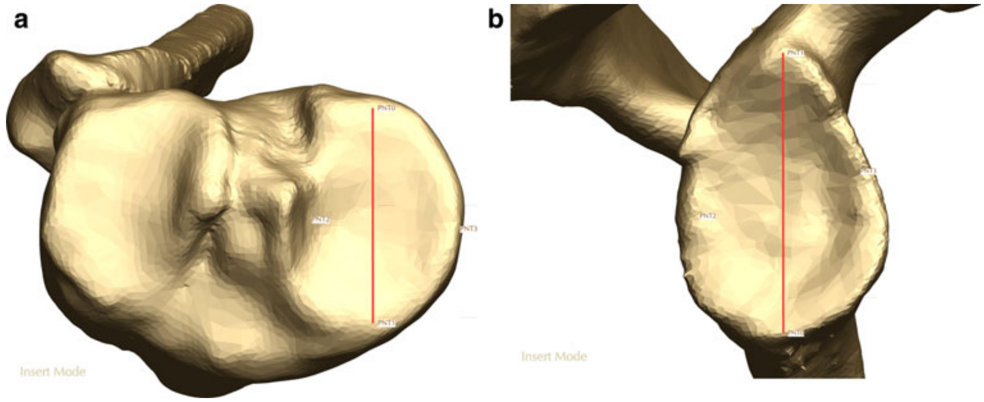

Fig. 1 **a** Measurement location for the medial tibial plateau length. **b** Measurement location for the glenoid surface length

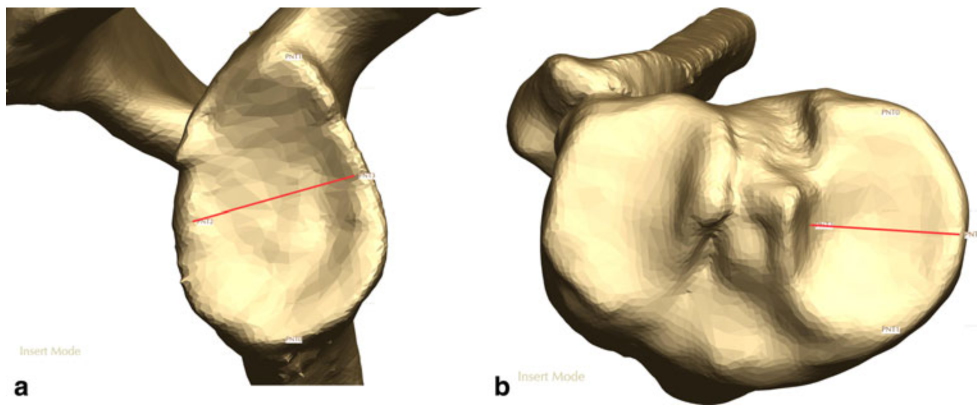

Fig. 2 **a** Measurement location for the glenoid surface width. **b** Measurement location for the medial tibial plateau width

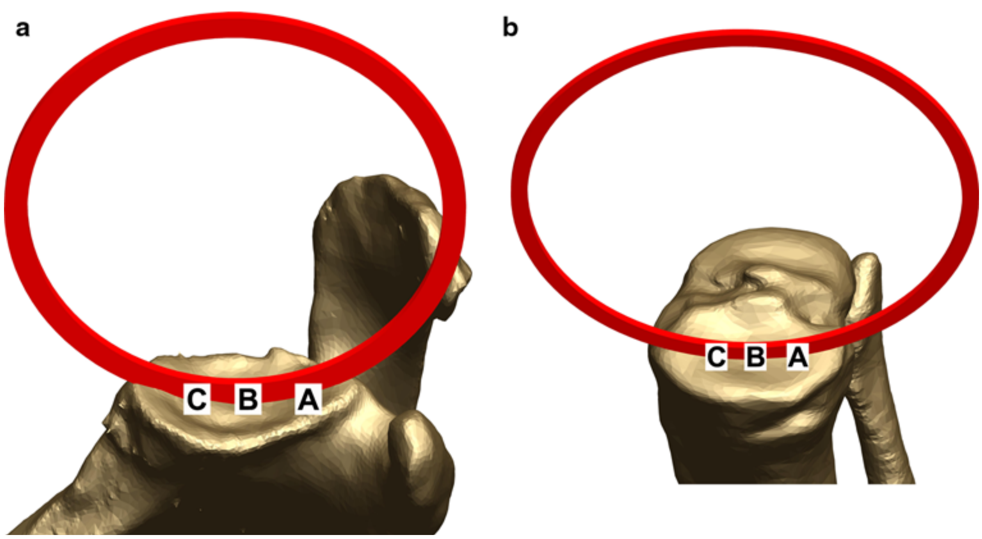

Fig. 3 **a** Radius of curvature in the coronal plane of the glenoid surface at segments *ABC*. **b** Radius of curvature in the sagittal plane of the medial tibial plateau at segments *ABC*

Given the poor results of shoulder arthroplasty in young patients, alternative surgical treatments are available but success is not as good as desired. Some of the available options are interposition arthroplasty with or without hemiarthroplasty using graft options: anterior capsule, fascia lata, achilles allograft, lateral meniscal allograft, dura mater, and porcine submucosa. Satisfaction results have been reported as follows: 50 % excellent, 36 % satisfactory, and 14 % unsatisfactory for biologic glenoid resurfacing with hemiarthroplasty [5].

Studies have previously focused on documenting glenoid anatomic characteristics such as size, inclination, and version [1, 4, 8]. The morphology of the scapula has been studied mainly for prosthesis implant placement and orientation [4], but further information may be useful due to new trends to treat chondral problems in young patients in a biological way. To appropriately resurface a joint, the donor graft must anatomically match the native surface to be reconstructed; therefore, we have undertaken this study to compare the convexity of the glenoid with that of the medial proximal tibia to ascertain whether this would be an appropriate source for osteochondral allografting. This is relevant as one of the current principal limitations in the United States of America for glenoid resurfacing is fresh glenoid allograft availability. Presently, medial tibial plateau grafts are much more widely available [8].

The study hypothesis was focused on the concept that there is a similar anatomic relationship between the glenoid and the medial tibial plateau based on clinical observations. This concept is important in determining whether medial tibia plateau allografts could be used as inlay glenoid allografts for glenoid reconstruction in joint-preserving surgery. There are published techniques using distal tibia as an allograft source for instability and bone loss procedures, but the anatomic relationships between the joint and graft surfaces have never been studied to our knowledge [7].

Materials and methods

Twenty computed tomography (CT) (Aquillion 64, Toshiba America Medical Systems, Tustin, CA) scans were randomly selected including five male and five female scapulas and five male and five female tibias. All of our CT scans were obtained from patients without significant glenoid or tibial deformity or arthritis. Factors such as age, race, or body mass index were not taken into consideration. The median age of scapulas was 32 years (range 21–66), and the median age of tibias was 28 years (range 22–41).

A sequence of images from the CT scan, representing slices of 0.5 mm thickness with a resolution of 512 × 512 pixels (i.e. voxel size of $\sim 0.7 \times 0.7 \times 0.5$ mm^3), were obtained using the standard 120-kVp and 200-mA bone reconstruction technique. Commercial software (Mimics, Materialize, Inc., Plymouth, MI) was used to extract the bone contours from the CT images and to reconstruct the 3D geometry of the scapula and tibia. By utilizing a commercially available 3D modelling software (Creo Elements/Pro 5.0, Parametric Technology Corp., Needham, MA), we calculated length and width of the articular surface for each of the 10 tibias and 10 glenoids. Length was obtained by measuring the distance between two points that were designated by two different observers in the sagittal plane for the tibias and in the coronal plane for the glenoids (Fig. 1). Width was calculated in the same fashion using the transverse plane for the center of the glenoids and the coronal plane for the tibias (Fig. 2).

The same two points that were used to calculate the length were used along with a point defining the center of the surfaces to create the plane for the radius of curvature in the coronal plane for the glenoids and in the sagittal plane for the tibias (ABC) (Fig. 3). The same points used to calculate width with the additional point in the center were used to measure the radius of curvature of the glenoids in the transverse plane (B, 50 %) (Fig. 4). Six additional points were marked between mutual agreement of both observers above and below the center along the length axis to calculate the transverse radius of curvature for the superior (A, 25 %) and inferior aspect of the glenoids in a similar fashion including the width across the surface in that plane and a central point (C, 75 %) (Fig. 5). Radius of curvature for the tibias was calculated in the same way in a sagittal plane (Fig. 6).

Statistical analysis

Statistical analysis was performed using Predictive Analytics Software (PASW) Statistics Version 18 (IBM Corporation, Armonk, NY). The study compared data for each measurement using a one-way analysis of variance (ANOVA) with a post hoc Tukey's honestly significant difference (HSD) test. Significant difference was determined to be present for $P < 0.05$.

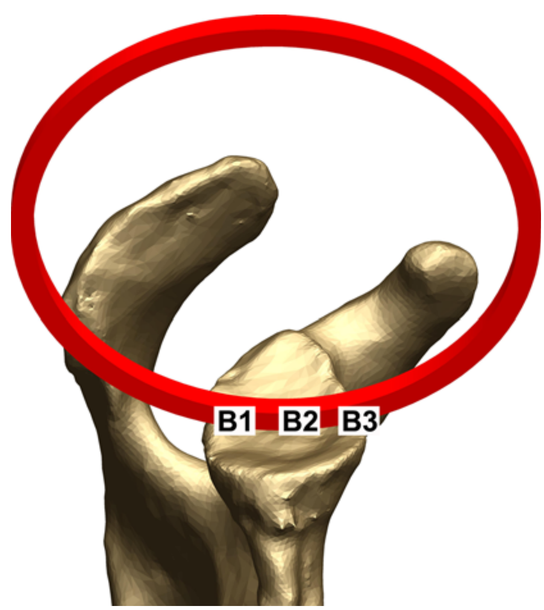

Fig. 4 Transverse radius of curvature of the glenoid surface at segment B (50 %), points 1, 2, and 3

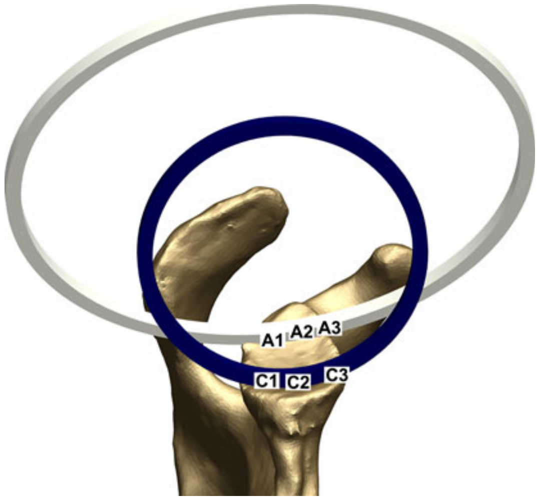

Fig. 5 Transverse radius of curvature at the superior and inferior aspects of the glenoid surface at segments *A* and *C* (25, 75 %)

Results

For the glenoids mean length was 34.0 ± 2.9 mm, and mean width was 24.4 ± 2.3 mm. The mean length of the tibial plateaus was 42.6 ± 2.7 mm, and mean width was 23.3 ± 4.3 mm. The ANOVA demonstrated that there was no statistically significant difference in either length or width.

Out of the eighty calculations done to obtain the concave radius of curvature, nine (11 %) were outliers because the surfaces were nearly flat or convex at those segments. Most of the flat segments were encountered in the same location: three in the posterior segment of the medial (A) tibial plateaus and two in the superior segment (A) of the glenoids. Only one glenoid had flat measurements at all the three sites where it was measured (A, B, and C). There were two measurements that were considered flat for two tibias in the sagittal plane (ABC).

The mean radius of curvature results for the glenoids that were calculated at four different segments (A, B, C, and ABC) were the following: A = 47.4 ± 17.5 mm, B = 51.2 ± 12.4 mm, C = 45.9 ± 17.0 mm, and ABC = 39.9 ± 8.8 mm. For the medial tibial plateaus, radius of curvature results at the four different segments (A, B, C, and ABC) were the following: A = 43.5 ± 9.7 mm, B = 37.4 ± 14.3 mm, C = 52.3 ± 21.5 mm, and ABC = 50.2 ± 9.9 mm (Table 1). We have found no statistical difference in the radius of curvature and dimensional surface area between the glenoid and medial tibial plateau surfaces (n.s.).

Discussion

The most significant finding in this study is that our study demonstrates that the convexity of the medial tibial plateau is very similar to that of the glenoid, despite the anatomical variance of the glenoid depending on race, gender, and age [3]. To view this specifically, two concave surfaces were generated to mimic the results of the averages from the sizes and radius of curvatures from the glenoids and medial tibial plateaus, and these surfaces were overlayed to show the similar shape and sizes (Fig. 7).

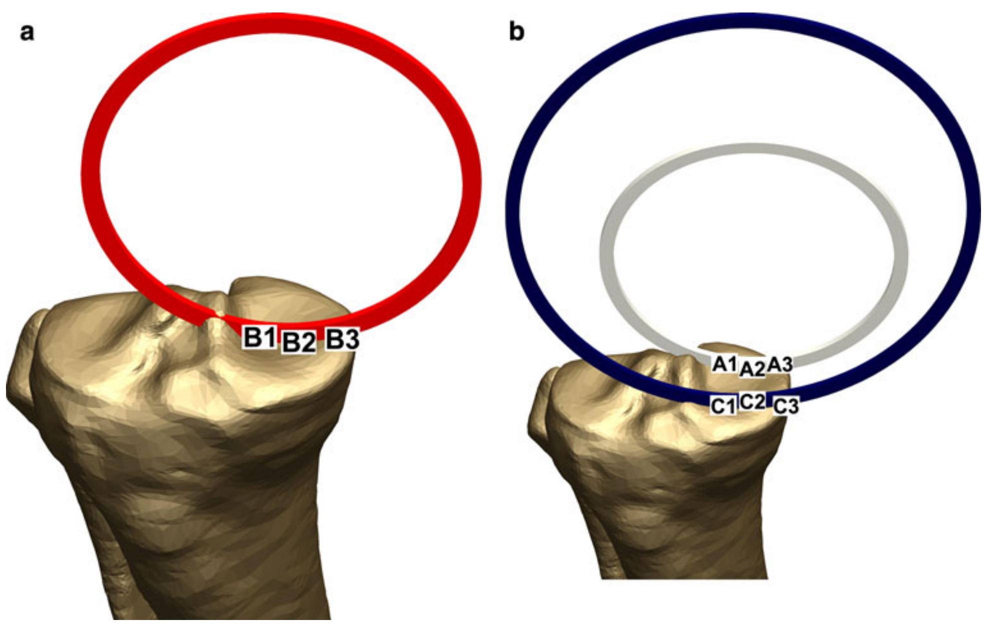

Fig. 6 **a** Sagittal radius of curvature of the medial tibial plateau at segment B (50 %). **b** Sagittal radius of curvature at the anterior and posterior aspects of medial tibial plateau at segments *A* and *C* (25, 75 %)

Table 1 Mean radius of curvature and standard deviation by segment

	A	B	C	ABC
Glenoids	47.4 mm (±17.5)	51.2 mm (±12.4)	45.9 mm (±17.0)	39.9 mm (±8.8)
Tibias	43.5 mm (±9.7)	37.4 mm (±14.3)	52.3 mm (±21.5)	50.2 mm (±9.9)

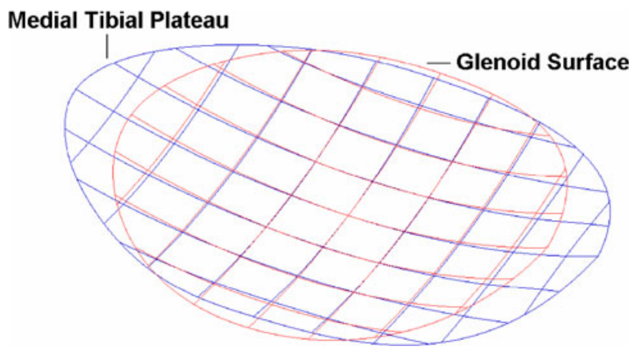

Fig. 7 Overlaying of the average surfaces of the glenoid and medial tibial plateau surfaces as derived by the measurements

An analysis of our results may help guide selection and preparation of specific regions of the allograft to match the native glenoid convexity. This may be accomplished by breaking the anatomy down into sections (A, B, or C) using the results in Table 1 and choosing the section that is more similar to the one we need to graft. The ideal setting when performing this inlay osteochondral allograft procedure may be either to use a glenoid allograft or to specifically match the patient's glenoid with a donor's tibial plateau based off of nearly matching tomography shape. Currently, this is difficult secondary to glenoid allograft availability, CT capabilities of allograft suppliers, and elevated surgical costs. Therefore, performing a transplant with a medial tibial plateau may be a viable option to perform an inlay glenoid allograft transplant at this time based on the averages of the results found in this paper.

Another advantage of our proposed technique is that we have wanted to achieve as much coverage as possible when performing the transplants. This would require the use of two mega plugs (one inferior and one superior) in order to cover between 80 and 90 % of the articular surface of the glenoid. With this in mind, the cartilage thickness will be equal throughout most of the articular surface.

One of the limitations of our study is that although the 3D CTs were randomly selected and those with known underlying bony pathology were excluded, there were still areas of flattening in certain cases. However, even in light of this, our calculations showed that there was no statistically significant difference giving more power to our study. By our experience, we know that when requesting these allografts, suppliers are usually careful in selecting young cadavers without bone or cartilage pathology.

Similarities between the cartilage thickness of the donor and recipient sites should be considered and discussed. Osteochondral autografts are transplanted to other joints, such as the knee, from the edges of the trochlea where it has been described that the cartilage is thinner than the recipient sites [9, 10], and these procedures have been performed with good to excellent results [2, 3, 6]. Performing cartilage thickness studies with magnetic resonance imaging (MRI) was considered when planning this study. While performing initial research, we found that sensitivity and specificity are difficult to control when performing this analysis [11], especially with MRIs performed at two different joints where the MRI scanners use different coils. However, fidelity is quickly changing and getting better with advancements in technology. MRI measurements may be something to consider for future studies, as it would pertain to all cartilage grafting techniques.

Due to the limitations in allograft availability in close relation to a scientific evolvement of glenoid osteochondral allografting, this study demonstrates how medial proximal tibia allografts that are more readily available can be used when performing inlay glenoid allograft transplantation.

Conclusion

The study did prove that there is a similarity in terms of convexity and size between the surface of the glenoid and the medial tibial plateau. This concept allows us to consider use of the medial tibial plateau as an anatomic source for grafting osteochondral allografts to be transplanted in the glenoid. Further research is needed to describe the technique of grafting and clinical outcomes.

Conflict of interest The Steadman Philippon Research Institute is a 501(c)(3) non-profit institution supported financially by private donations, and corporate support was received from the following entities: Smith & Nephew Endoscopy, Inc., Arthrex, Inc., Siemens Medical Solutions USA, Inc., ConMed Linvatec, Inc., Össur Americas, Inc., Small Bone Innovations, Inc., Opedix, Inc., Evidence Based Apparel, and Sonoma Orthopedics, Inc.

References

1. Churchill RS, Brems JJ, Kotschi H (2001) Glenoid size, inclination, and version: an anatomic study. J Shoulder Elbow Surg 10:327–332

2. Demange M, Gomoll AH (2012) The use of osteochondral allografts in the management of cartilage defects. Curr Rev Musculoskelet Med 5:229–235
3. Gomoll AH, Farr J, Gillogly SD, Kercher JS, Minas T (2011) Surgical management of articular cartilage defects of the knee. Instr Course Lect 60:461–483
4. Hoenecke HR Jr, Hermida JC, Flores-Hernandez C, D'Lima DD (2010) Accuracy of CT-based measurements of glenoid version for total shoulder arthroplasty. J Shoulder Elbow Surg 19:166–171
5. Krishnan SG, Nowinski RJ, Harrison D, Burkhead WZ (2007) Humeral hemiarthroplasty with biologic resurfacing of the glenoid for glenohumeral arthritis. Two to fifteen-year outcomes. J Bone Joint Surg Am 89(4):727–734
6. Lattermann C, Romine SE (2009) Osteochondral allografts: state of the art. Clin Sports Med 28:285–301
7. Maurer A, Fucentese SF, Pfirrmann CW, Wirth SH, Djahangiri A, Jost B, Gerber C (2011) Assessment of glenoid inclination on routine clinical radiographs and computed tomography examinations of the shoulder. J Shoulder Elbow Surg 21:1096–1103
8. Provencher MT, Ghodadra N, LeClere L, Solomon DJ, Romeo AA (2009) Anatomic osteochondral glenoid reconstruction for recurrent glenohumeral instability with glenoid deficiency using a distal tibia allograft. Arthroscopy 25:446–452
9. Shepherd DE, Seedhom BB (1999) Thickness of human articular cartilage in joints of the lower limb. Ann Rheum Dis 58:27–34
10. Thaunat M, Couchon S, Lunn J, Charrois O, Fallet L, Beaufils P (2007) Cartilage thickness matching of selected donor and recipient sites for osteochondral autografting of the medial femoral condyle. Knee Surg Sports Traumatol Arthrosc 15:381–386
11. Yeh LR, Kwak S, Kim YS, Chou DS, Muhle C, Skaf A, Trudell D, Resnick D (1998) Evaluation of articular cartilage thickness of the humeral head and the glenoid fossa by MR arthrography: anatomic correlation in cadavers. Skeletal Radiol 27:500–504