Three-Dimensional Morphometric Analysis of the Distal Femur: A Novel Method for Allograft Selection Using a Virtual Bone Bank

INTRODUCTION:
Tumor excision with wide surgical margins is the primary treatment of aggressive or recurrent benign bone tumors and malignant bone sarcomas. This requires a surgical resection, with the potential for large residual osseous defects. As diagnostic and therapeutic techniques improve, patients with musculoskeletal sarcomas should expect increased survival, decreased complications and side-effects, and an improved quality of life. Functional longevity of the reconstruction becomes a major concern, especially in young and physically active patients. Emphasis has been placed on biologic reconstructive alternatives due to concerns involving the durability of prosthetic materials, and the increasing survivorship of patients with sarcomas. Poor anatomical matching of both size and shape between the host and the donor can significantly alter joint kinematics and load distribution, leading to articular fractures or joint degeneration. Determining the size and shape of the distal femur is critical for obtaining an appropriate allograft. In addition to this, it is difficult to plan an allograft on a distal femur deformed by the tumor (Fig 2a,b).

The objective of this study was to develop a protocol for searching and selecting a best-match distal femoral allograft from a virtual bone bank, and to verify its intra- and inter-observer reliability. The feasibility of such protocol is based on our hypothesis, which states that the symmetry of the contralateral distal femur will provide the benchmark geometry for a best match in preoperative planning allograft selection (Fig 2a,b).

METHODS:
A total of thirty-three fresh-frozen whole femora were selected from the bone bank for this IRB-approved study, 15 right and 18 left (age range: 16-58, 35.9 ± 12.0; 22 males and 11 females) were scanned on a Toshiba Aquilion CT scanner, with a resolution of 0.877 pixels/mm and slice increments of 0.5 mm. 3D reconstructions of all specimens were created from CT images. The following distal femur morphometric parameters were measured with specialized 3D software (Mimics, Materialise, Belgium) on a plane perpendicular to the long axis of the bone (Fig 1): 1. Transepicondylar axis (A): the distance between the most medial point in the medial epicondyle and the most lateral point in the lateral epicondyle. 2. Medial condyle distance (B), determined as the distance between the most anterior and most posterior points, respectively, in the anterior-posterior direction. 3. Lastly, the length of the lateral condyle (C) determined with the same method used for the medial condyle (Fig 1). Intra- and inter-observer reliability of this protocol was assessed measuring 33 and 20 femora, respectively, and was evaluated using an intra-class correlation coefficient. Size symmetry was quantified with R square (R²) coefficient between right and left A-B-C measures from the same donor in 10 cases (Fig. 1). The allograft matching protocol uses point-cloud models derived from the CT reconstructions. First, a mirror image of the left femur is created. This ensures function and shape matching. Next, the selected match is superimposed onto the right femur using a volume-merge technique developed in our laboratory (Fig. 2c) [1]. Finally, the position and orientation of the overlapping point clouds are evaluated numerically using a custom-written visual C++ closest-point distance algorithm. This analysis was carried out for ten femur pairs (Fig. 2 C, D, E).

RESULTS:
Protocol metrics: A single operator was tested for intraobserver repeatability while using the above-mentioned A-B-C protocol twice on thirty-three distal femoral allografts, obtaining an intraclass correlation coefficient of 0.99 in almost all measures (Table 1). Interobserver consistency of two separate observers was quantified when they measured the A-B-C parameters of twenty distal femoral allografts leading to an intraclass correlation coefficient of 0.99 in all measures (Table 2). The R² coefficient between right and left side was 0.99 in the ten pairs evaluated (Fig 1). Shape compliance: Evaluation of the overlapped original and mirror point-cloud models with the custom C++ program found that the closest distance between points was 0.89±0.07 mm. This result is within the CT slice thickness of 0.5 mm and CT resolution of 0.877 pixel/mm.

DISCUSSION:
This work demonstrates the usefulness of three-dimensional models when searching and selecting the best similar host–donor allograft match and proves our symmetry hypothesis. The results suggest that a robust technique which provides, reliability, and most importantly, repeatability, has been established. The same method can then be used to match a candidate from the bone bank to the patient’s femur (Fig 2a,b). One limitation of this study is the small amount of samples. On the other hand, the results stemming from the use of this measurement protocol enable accurate selection of allografts from a contralateral healthy femur CT achieving the best match possible considering the geometry of available allograft candidate femur specimens.

REFERENCES: