Augmented Reality Guidance for Targeted Re-Resection of Positive Margins in Sarcoma

Michael J. Colello, MD[1], Riley S. Gilbertson, BA[1,2], Joaquin Austerlitz, BS[3], Andreja Radevic, BS[3], Sakshi Krishna, BS[1,2], Alexander N. Perez, MD[4], Reena Singh, MD[4], Jennifer Halpern, MD[1], Herbert S. Schwartz, MD[1], Michael C. Topf, MD[3], Daniel Johnson, MD[1], Joshua M. Lawrenz, MD[1]

[1] Division of Musculoskeletal Oncology, Department of Orthopaedic Surgery, Vanderbilt University Medical Center, Nashville, TN
[2] School of Medicine, Vanderbilt University, Nashville, TN
[3] Department of Otolaryngology–Head and Neck Surgery, Vanderbilt University Medical Center, Nashville, Tennessee, USA
[4] Department of Pathology, Microbiology and Immunology, Vanderbilt University Medical Center, Nashville, Tennessee, USA

**Presenting Author*
Michael J. Colello, MD
Mjcolello10@gmail.com

Riley S. Gilbertson, BA
riley.gilbertson@vumc.org

Joaquin Austerlitz, BS
joaquin.austerlitz@vumc.org

Andreja Radevic, BS
andreja.radevic@vumc.org

Sakshi Krishna, BS
sakshi.krishna.1@vumc.org

Alexander N. Perez, MD
alexander.n.perez@vumc.org

Reena Singh, MD
reena.singh@vumc.org

Herbert Schwartz, MD
herbert.s.schwartz@vumc.org

Jennifer Halpern, MD
jennifer.halpern@vumc.org

Michael C. Topf, MD
michael.topf@vumc.org

Daniel Johnson, MD
Daniel.johnson@vumc.org

Joshua Lawrenz, MD
joshua.lawrenz@vumc.org

Abstract

Significance & Hypothesis

Achieving negative surgical margins is paramount for local control in musculoskeletal oncology, with implications on both local recurrence and patient survival[1-3,5-8,12,15,16]. Depending on the location and histology of the sarcoma, positive margins can occur in 10-50% of cases and often require re-resection[1,4-7,11,12,15,16,18]. Conventional text-based pathology reports may fail to accurately communicate the complex three-dimensional (3D) location of a positive margin, leading to an imprecise re-resection that may miss residual disease or an unnecessarily morbid resection of un-involved tissue[9,10,13,14,17]. We hypothesize that projecting a 3D "digital twin" of the resected specimen back into the surgical bed using augmented reality (AR) can bridge this communication gap.

Innovation

We present the clinical implementation of a novel AR workflow to guide targeted re-resection of positive margins in sarcoma. Our study highlights a novel clinical application without existing literature on this topic in orthopaedic oncology.

Approach

Ex-vivo malignant soft tissue tumor specimens underwent 3D surface structured light scanning immediately following resection at a tertiary sarcoma center. All selected cases had positive margins requiring re-resection and staged soft tissue reconstruction. Virtual margin annotation was performed mirroring standard pathology grossing creating a “digital twin”, and a 3D margin heat map indicating distance to residual tumor with a gradient color scheme was created (Figure 1). The virtual specimen was then presented in multidisciplinary tumor board for discussion of surgical planning and adjuvant treatment. The annotated 3D specimen model was then imported into an Apple Vision Pro headset. Intraoperatively, the surgeon utilized the headset to spatially align the holographic projection of the specimen within the surgical wound bed (Figure 2). This allowed the virtual positive margin to "float" over the corresponding residual tissue and help guide the re-resection (Figure 3).

Results

Three patients underwent oncologic resection of a malignant soft tissue tumor with planned staged soft tissue reconstruction. One patient had a dorsal foot dermatofibrosarcoma protuberans (Figure 1), one patient had a pretibial myxofibrosarcoma (Figure 2), and one patient had a large truncal ulcerative basal cell carcinoma (Figure 3). After initial tumor resection, specimens were 3D scanned and annotated alongside the pathologist during grossing. Final pathology revealed positive margins in all 3 cases, necessitating re-resection prior to soft tissue reconstruction. The annotated models were loaded into the AR headset and used intraoperatively for localization of involved margins that were subsequently re-resected. Frozen sections from the guided re-resection specimens were obtained to confirm the presence of tumor. Final margins were negative in all cases and they underwent definitive soft tissue coverage.

Discussion & Impact

Intraoperative AR-guided re-resection of positive margins using 3D scanned specimens with virtual margin mapping is a novel tool in musculoskeletal oncology. We presented 3 cases using this method to successfully guide precise re-resection of positive margins. This translation of static histopathologic data into dynamic, intraoperative visual guidance has the potential to improve surgical outcomes, aid in multidisciplinary communication and clinical decision-making, and be a valuable educational tool.

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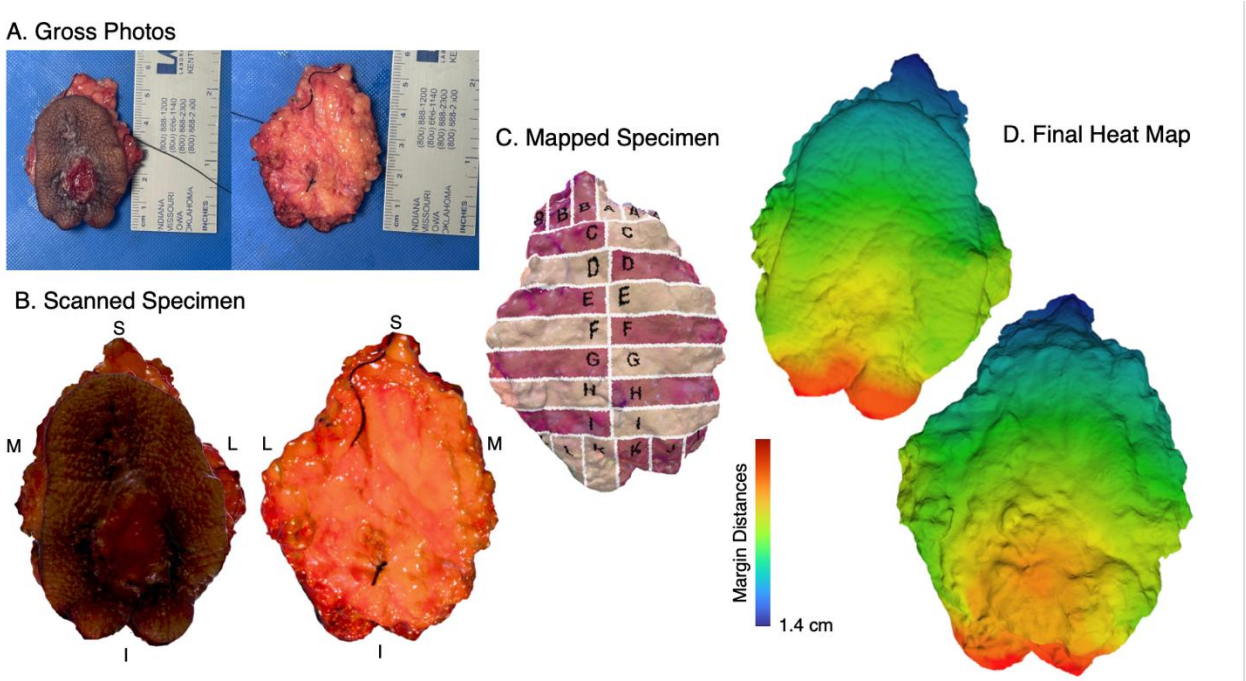

Figure 1: Representative gross photos, three-dimensional (3D) scan, mapped specimen, and margin heat map for a left dorsal foot dermatofibrosarcoma. (**A**) Gross photos of the specimen. (**B**) Superficial and deep surfaces of the 3D scanned specimen. (**C**) Deep surface of the specimen with pathology slices mapped, positive margin indicated by letter "K" (**D**) Final heat map of the specimen with a positive margin, indicated in orange. S: Superior; M: Medial; L: Lateral; I: Inferior.

Figure 2: (**A**) View from inside the AR headset during intraoperative guidance. A holographic projection of the mapped tumor is overlayed into the previous resection bed to localize the area of positive margin. (**B**) View of the surgeon utilizing the AR headset intraoperatively.

Figure 3: The area of positive margin drawn in purple within the previous resection bed that was localized using AR guidance. This area was then resected with a final negative margin.