

Surgical Simulation Maximizing the Use of Fresh-Frozen Cadaveric Specimens: Examination of Tissue Integrity Using Ultrasound

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ABSTRACT

Background Arthroscopic surgical simulation, including the use of cadaveric tissue, is valuable for training orthopedic surgery residents. However, it is unclear how often fresh-frozen cadaveric tissue can be reused to provide a reproducible model for developing arthroscopic skills.

Objective We determined the usefulness of ultrasound in evaluating tissue degradation in fresh-frozen shoulder and knee joints used for surgical simulation.

Methods Between February 7 and April 11, 2017, orthopedic residents participated in 6 wet lab sessions during 1 rotation. Knee and shoulder specimens were subjected to ultrasound using a SonoSite Edge machine and a linear probe after each freeze-and-thaw cycle. Degradation of each structure was determined based on standards created for living tissue and comparisons to previous images of the same tissue before initial use.

Results Ultrasonographic assessment of the 2 knee and 2 shoulder specimens revealed lost integrity in subcutaneous fat and muscle with evidence of increased hypoechoicity and loss of normal fiber orientation and density in all specimens examined. Tendons, ligaments, cartilage, iliotibial band, and bone did not lose integrity during freezing and thawing. Ultrasonographic assessment revealed no loss of joint structure integrity. However, the intra-articular work assigned for the simulation curriculum had been carried out to a degree that by the third use, little opportunity remained for further arthroscopic practice on that specimen.

Conclusions In this study, ultrasound findings showed that fresh-frozen shoulder and knee specimens maintained structural integrity useful for simulation training after 3 cycles of freezing.

Introduction

Graduates from orthopedic surgery residency programs are expected to possess a high degree of surgical confidence and competence. Work-hour constraints, increasing complexity of cases, and stricter supervisory protocols have limited the amount of operating room exposure, correlating with a reduction in postresidency operative confidence.¹⁻⁵ Therefore, surgical simulation, including simulation for arthroscopy, has become more popular to accommodate for the decrease in operative opportunities during residency.⁶⁻¹⁸ This has advanced the development of models, virtual reality, and use of cadaveric tissue from whole-body donors as simulation tools.¹⁹

Simulation models available for arthroscopic training vary greatly in cost and applicability (provided as

online supplemental material). Dry workstations and models cannot handle normal tissues and require frequent replacement of utilized parts. Advanced simulators, which cost \$110,000 to \$160,000 plus annual service contracts, may be out of reach for many programs. The use of whole-body donors in surgical training provides a better model for understanding anatomy and manipulation, and it has been linked with an increase in operative skill confidence.²⁰ However, human cadaveric tissue allows only a finite number of training sessions due to deterioration of tissue quality, with a cost or reimbursement rate of approximately \$500 to \$600 for a disarticulated shoulder or knee specimen.

Our efforts to minimize the cost of arthroscopy simulation, along with our desire to maximize the gift of our human tissue donors, led us to explore the process of utilization and reutilization of fresh-frozen tissue specimens. Ultrasound has been increasingly utilized in clinical medicine to evaluate the echogenicity, thickness, and patterns of organization of soft tissues, particularly muscle, in the setting of injury and metabolic disease. Potentially, these principles could apply to donor materials as well. To our

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Editor's Note: The online version of this article contains a cost comparison for various available tools for resident arthroscopy simulation training and the schedule of resident arthroscopic surgical simulation laboratory work over the course of a 10-week orthopedic sports surgery rotation.

knowledge, the use of ultrasound to evaluate donor tissue has not been previously investigated.

We hypothesized that ultrasound examination of the cadaveric tissue would aid in our ability to quantify the degradation of the tissues in fresh-frozen shoulder and knee joints and, thereby enhance our ability to maximize our whole-body donor gifts for the education of our residents.

Methods

The study was conducted between February 7 and April 11, 2017, at a university-based orthopedic residency program with 25 residents. Residents participate in six 4-hour wet lab sessions over the course of a 10-week rotation as postgraduate year (PGY) 3 and PGY-5 trainees (schedule provided as online supplemental material). Two fresh-frozen knees and 2 fresh-frozen shoulders are utilized over the course of the rotation. In all, each specimen is utilized 3 times and refrozen between uses. We noted that while the muscle tissue of the specimen degraded by the end of the rotation, the joints and surrounding tendons appeared to be less affected by repeated freeze-and-thaw cycles.

At our institution, cadaveric materials are secured through the Body Donation Program. Donors arrive within 48 hours of death, and serology is performed for human immunodeficiency virus and hepatitis B and C. Prior to their first freeze cycle, pathology-negative donors undergo a bowel cleansing, oral and nasal cleansing and aspiration, followed by an antibacterial wash of the entire body surface. Donors are then dried and stored in a freezer at 20°F to 25°F until use.

For surgical training purposes, knee and shoulder specimens are removed from the donor either prior to or after freezing without significant thawing. Specimens are then stored at 20°F to 25°F. For use, the specimens are relocated to a cooler to undergo thawing at 37°F. During the 4-hour laboratory session, the residents practice arthroscopic procedures using the thawed specimen. After use, specimens are rewashed with antibacterial wash, placed in a sealed plastic storage bag, and returned to a 20°F to 25°F freezer until required for use again. The knee and shoulder specimens were subjected to ultrasound after each freeze-and-thaw cycle to assess how freezing and thawing affect the tissue. All tissue was assessed using a SonoSite Edge machine (SonoSite Inc, Bothell, WA) using a linear HLF 50 (15 MHz) probe. Ultrasound images were collected in long axis view—meaning the probe was placed in plane with the main structure in the image.

What was known and gap

Arthroscopic surgical simulation use of cadaveric tissue is valuable for training orthopedic surgery residents, but it is unclear how often fresh-frozen cadaveric tissue can be reused to provide a reproducible model for developing arthroscopic skills.

What is new

A study testing the usefulness of ultrasound to evaluate tissue degradation in fresh-frozen shoulder and knee joints used for surgical simulation.

Limitations

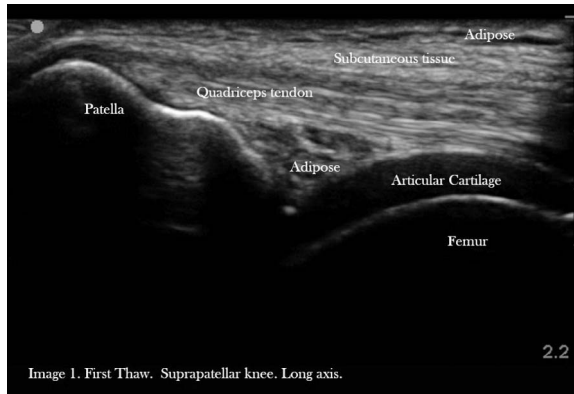
There was only 1 expert ultrasound reviewer at 1 institution with a small number of knee and shoulder specimens, limiting generalizability.

Bottom line

Fresh-frozen knee and shoulder specimens maintained structural integrity useful for simulation training after 3 cycles of freezing.

The rating of tissue quality on ultrasound is necessarily subjective but based on standards established for assessing living tissue in clinical subjects evaluated for injury and metabolic disorders.²¹ The ultrasound technician (R.C.P.) was a sports medicine primary care physician whose clinical practice involves the frequent use of ultrasound for tissue assessment and guidance of percutaneous procedures. Tissues that demonstrated obvious change from the first to the third thaw were considered by the ultrasound technician to have lost integrity, while tissues that did not demonstrate change were considered to have maintained integrity. The technician was not blinded to the number of thaws due to the progressive nature of the schedule. The normal tissue integrity was examined closely at the first use and assessed by comparison of the structure's appearance on ultrasound as the specimen was refrozen and utilized again in lab sessions. Each tissue type has a characteristic appearance. Adipose, tendons, muscles, and ligaments all have similar appearance throughout the body. Healthy muscles and healthy tendons were the core structures assessed in this study. The deeper structures, including the cruciate ligaments and meniscus, are not well visualized with ultrasound. Change in tissue appearance on ultrasound between sessions was assessed as a loss of tissue integrity. Less organized tissue and darker tissue, referred to as *hypoechoic*, were categorized as decreased integrity of the tissue.²² This is theoretically related to degradation of the muscle and subcutaneous tissue during the freeze-and-thaw cycles.

This study was exempt from Institutional Review Board approval by Oregon Health & Science University.

**FIGURE 1****Knee: Long Axis View, First Thaw**

Note: The left knee just proximal to the patella over the quadriceps tendon in long axis view. The image was taken after the first thaw. The tissues look similar to living human tissue. The linear fibers of the quadriceps tendon are clearly visible. The hypoechoic (black) space on the image is shadow from the bone.

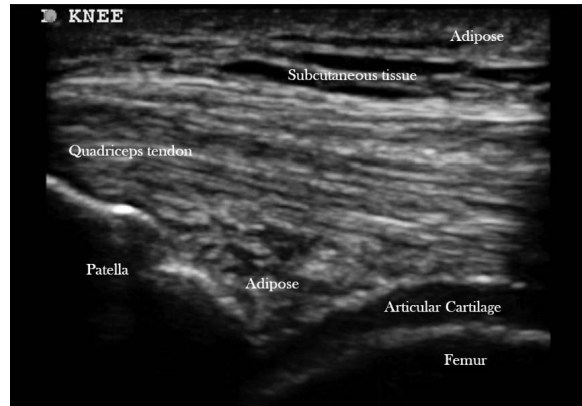
Results

Two knees and 2 shoulders were imaged at the start of the 3 simulation sessions assigned to each specimen during the 10-week training period. In general, the tissue maintained reasonable integrity throughout the freeze-and-thaw cycles. The 2 tissues that lost integrity from ultrasonographic assessment in all specimens were subcutaneous fat and muscle. Both of these tissues showed evidence of loss of normal ultrasound appearance in the form of increased hypoechoicity and loss of normal architecture (orientation and density of fibers). Examples of this are seen in FIGURES 1 through 4.

FIGURES 1 and 2 show the knee just proximal to the patella over the quadriceps tendon in long axis. The ultrasound appearance after the first thaw (FIGURE 1) and after the third thaw (FIGURE 2) are shown. The subcutaneous tissue and adipose are hypoechoic after the third thaw. The tendons, ligaments, articular cartilage, iliotibial band, and bone did not lose integrity during the thaws in any of the specimens. FIGURES 3 and 4 demonstrate this process of tissue breakdown in the case of the vastus medialis muscle and its neighboring subcutaneous fat.

Discussion

Most musculoskeletal ultrasound applications focus on the tendons, ligaments, joint capsules, fascia, and other connective tissues. These structures all appear to have minimal breakdown and are therefore useful for this application after up to 3 freeze-and-thaw cycles. Some intra-articular artifact was seen in the infrapatellar fat pad from the arthroscopic interventions (FIGURE 5). Evaluation of the tissue on

**FIGURE 2****Knee: Long Axis View, Third Thaw**

Note: The knee from FIGURE 1 after the third thaw. Compared with FIGURE 1, the subcutaneous tissues/adipose layer is more black, or hypoechoic, indicating decreased integrity of the tissue. In addition, the quadriceps tendon has less organization and is more hypoechoic, also representing some tissue degradation. The bone and articular cartilage appear to have minimal to no degradation.

ultrasound indicated preserved intra-articular structures, which correlated with the learner's perception of the preserved intra-articular tissue integrity (ie, consistent with that of fresh or single-thaw fresh-frozen tissue) when training on the specimens with arthroscopy.

Our study demonstrated that knee and shoulder cadaveric tissue specimens can be refrozen and utilized up to 3 times each without significant degradation of the critical tissues needed for arthroscopic simulation. While the surrounding muscle and subcutaneous tissue demonstrated notable degradation on ultrasound, the appearance of the capsule and intra-articular structures did not change. Thus, our program currently uses its cadaveric arthroscopy specimens for 3 simulation sessions.

**FIGURE 3****Knee: Vastus Medialis, First Thaw**

Note: The vastus medialis taken in long axis view after the first thaw. These tissues look similar to living human tissue. The vastus medialis has mixed ultrasound signal with septations and appreciable muscle fiber texture. The hypoechoic space (black) on the image is shadow from the bone.

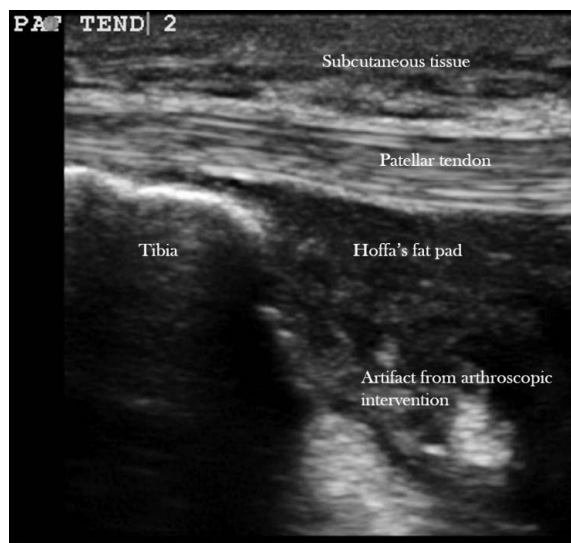
**FIGURE 4****Knee: Vastus Medialis, Third Thaw**

Note: The vastus medialis from FIGURE 3; however, the image was taken after the third thaw. Compared with FIGURE 3, the subcutaneous tissues/adipose layer is more hypoechoic. This indicates decreased integrity of the tissue. Similar to the quadriceps tendon, the vastus medialis muscle has less definition and loss of organization of muscle fiber appearance with increased hypoechoic signal representing tissue degradation. The bone shows no degradation.

To our knowledge, this is the first study to assess the feasibility of fresh-frozen specimen reutilization for the development of resident arthroscopic skills. While we have no other literature comparison, the methods used for assessing tissue viability were those used for clinical determination.²⁰ The appearance of the muscle tissue was similar to that of muscle afflicted by sarcopenia²² after several thaws, indicating degradation of the muscle with reuse. By comparison, the appearance of the intra-articular structures did not change, indicating that the joints remained well preserved as the specimen was reutilized.

The ability to reutilize fresh and fresh-frozen tissue reduces the cost associated with wet lab-based arthroscopic simulation. The ability of ultrasound to confirm our anecdotal experience that different tissues exhibit degradation at varying rates has implications for surgical simulation in all disciplines: procedures requiring optimal muscle integrity can be prioritized for first use, and procedures requiring only intracapsular integrity can be saved for later use. With careful attention to the procedure location and invasiveness, costs can be minimized, and donors' gifts maximized, by sharing the donor tissue and reutilizing it over several sessions among shared disciplines.

One limitation of human donor tissue as a simulation substrate is that most donors are older. This was the case in our study, which increased the likelihood of degenerative disease in the joint. Because they were evaluated in comparison to their own time-zero appearance on ultrasound (rather than based on comparison to other donors or clinically

**FIGURE 5****Knee: Infrapatellar Fat Pad, Third Thaw**

Note: The infrapatellar Hoffa fat pad artifact taken in long axis view after the third thaw. This change in morphology of the infrapatellar fat pad was the only evidence of prior insult to the tissue used multiple times.

normal controls), and because much of the literature on muscle appearance on ultrasound is based on sarcopenia in older patients, the evaluation on ultrasound should be valid. In addition, sectioning donor specimens can change the alignment of tissues, for example, in sag of the patella or the humeral head relative to the knee or shoulder joint. Study limitations are that there was only 1 expert ultrasound reviewer at 1 institution with a small number of knee and shoulder specimens. Currently there are no metrics to objectively quantify the degree of degradation of tissue with ultrasound. This could produce subjectivity in tissue assessment and differing findings if the study had included more than 1 assessor.

Future studies should focus on the appearance of other anatomical locations to evaluate how these findings might change in anatomical regions that are more or less dense in muscular tissue, which showed the most change in our study. It is our hope that the information presented in this work can provide a foundation for a model of surgical simulation that uses and reuses donor gifts to their maximum potential in order to optimize surgical training.

Conclusions

Using ultrasound, fresh-frozen knee and shoulder specimens were judged to maintain structural integrity useful for simulation training after 3 cycles of freezing without degradation of the critical intra-articular structures of the joint. This finding may

prolong the use of body-donor gifts while supporting surgical training.

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