A novel embalming technique preserves cadaveric wrist biomechanics over extended periods of time

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Purpose: Fresh-frozen, thawed (FF/T) human cadaveric specimens are considered the gold standard of living tissue analogues as they most closely represent an in vivo state. However, FF/T tissues pose problems when being used in a research environment. Because tissue decay is only suspended while the specimen is fully frozen, thawing the specimen starts the decay process, which can significantly degrade the specimen after as little as 72 hours. Furthermore, the use of these tissues can include a risk of potential infection. To address these issues, tissues are commonly preserved, or embalmed, through employing chemical treatment techniques, such as formalin-fixation, that allow for the tissues to last longer and remove the risk of infection. However, techniques like formalin-fixation also result in cross-linking the soft tissues to the cytoskeleton, which causes a notable increase in tissue stiffness often to near-rigidity. Because these properties are no longer typical of in vivo tissue, it makes it impossible to meaningfully compare any findings to their in vivo counterpart. A relatively new method of phenol-based “soft”-embalming (SE) has been reported to preserve tissues in a FF/T-like state as compared to the formalin-fixation methods, while still providing the benefits of tissue preservation and mitigating risk of infection. If successful, this method of embalming may prove to be an attractive alternative to using FF/T tissue as an in vivo tissue analogue.

The purpose of this study was to investigate the longer-term effects of the SE process on FF/T tissues to determine if the tissues remained reasonably comparable to the in vivo state, firstly 7-10 days after being embalmed, then again 6 months later. The goal of the investigation was to determine whether such soft-embalmed tissues would make for an appropriate, comparable alternative to FF/T tissues for use as an in vivo analogue with sufficient stability over time for detailed biomechanical investigations.

Methods: 4 fresh-frozen forearms were obtained and fully thawed prior to any testing. Each specimen had multiple radio-opaque beads implanted within the distal radius and in the 3rd metacarpal (both base and head). These beads have been demonstrated to provide reliable fiducial landmarks for radiographic data analysis. The specimen was immobilized in a stabilization apparatus that held the forearm in place, but allowed the wrist to deviate primarily in the radial and ulnar directions. The tendons recruited in vivo to perform a radioulnar deviation (Flexor Carpi Radialis and Ulnaris and Extensor Carpi Radialis Longus, Brevis and Ulnaris) were dissected and activated in an active loading protocol of increasing force that allowed each specimen to deviate in the radial and ulnar directions, respectively, until the maximum range of motion was reached. At each loading point, a General Electric Innova Cone-Beam CT (CBCT) 3D scan was taken. After the maximum ranges were found, the specimen was soft-embalmed for 7-10 days to ensure full tissue saturation, and the loading protocol was repeated, CBCT-scans inclusive. The tissues were refrigerated in a soft-embalmed state for 6 months, on average, and the loading protocol (with CBCT scans) was repeated a third time. Following each loading protocol execution, the positions of the radio-opaque beads were segmented from the 3D volumes and used to determine the amount of radioulnar deviation for each specimen in each tissue state: FF/T, SE, and SE after 6 months (SE6).
Results: The radial and ulnar deviation end-range of motion patterns were similar in all specimens in all tissue states, and typical of in vivo results. The end-ranges for each specimen in all tissue states were found to be statistically equivalent to within ± 3 degrees of radioulnar deviation with 95% confidence (3D rendering in Fig. 1).

3D renderings of maximum radial and ulnar deviations in FF/T (a), SE6 (b), and a combined overlay (c), where FF/T is colored magenta, SE6 in green, and reference bone in blue. Note that the overlapping region in (c) will appear black in print.

Conclusions: The soft-embalmed specimens provide qualitatively and quantitatively similar behavior to fresh frozen, thawed tissue, both immediately after embalming and following six months of storage. They do not suffer from the drawbacks, such as short time-restrictions and risk of infection, that are present when using FF/T tissues. Furthermore, they remain stable for months following the initial embalming. Based on these findings, the SE specimens appear to be a promising alternative for use as an in vivo tissue analogue and will allow for extensive studies, specifically those beyond 72 hours, in orthopedic biomechanical research and surgical navigation. However, further investigation is necessary to verify that detailed, intercarpal kinematics show the same fidelity exhibited in the gross motion.