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# Investigating the mechanical properties of Thiel-embalmed metatarsals

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**ABSTRACT**

**Introduction:** Fresh-frozen cadaveric samples are often utilized for research and the study of anatomy. Thiel embalming offers the possibility of preserving human tissue and bone without requiring special freezing equipment. Thus mechanically testing Thiel embalmed bone to compare with fresh frozen samples becomes increasingly important.
**Method:** The 1st and 5th metatarsals were harvested from 3 cadavers which had one foot fresh frozen and the other Thiel embalmed. These metatarsals underwent 3-point testing until fracture.
**Results:** 5th metatarsal average fracture force for Thiel embalmed and fresh frozen samples was equal to 305N (SD241N) and 539N (SD232N) respectively. Similarly average fracture force for Thiel embalmed and fresh frozen 1st metatarsals was equal to 614N (SD192N) and 694 (SD273N) respectively.
**Conclusion:** Thiel embalmed metatarsals yield at a lower force than fresh-frozen metatarsals obtained from the same cadaver. Thus one should be cautious about utilizing these preserved bones in situations where bone strength is required.

## 1. Introduction

In skeletal research, the use of bones harvested from cadaveric samples are normally indicated given the possible destructive nature of laboratory tests which would make the use of samples from living subjects both ethically challenging and impractical. Such tests aimed at investigating the mechanical properties of various types of bone normally utilize fresh-frozen bones, which are considered as the gold standard since freezing produces minimal changes to these bones (1,2). However, the use of fresh frozen cadaveric material carries with it the risk of infection, which can be hazardous to investigators (3,4).

Since nowadays fresh frozen cadavers are becoming scarcer in anatomy departments, while Thiel embalming, being more convenient, is becoming more popular, the importance of mechanically testing Thiel embalmed bone to compare with fresh frozen samples becomes increasingly important (5,6). This would determine whether the magnitude of the force that this type of preserved bones can withstand would be comparable to their fresh-frozen counterparts. Presently, there is a clear paucity of information relating to the testing of Thiel embalmed human bones.

Unger et al (2010) compared the mechanical properties of 3mm x 60mm cylindrical cortical specimens obtained from human femurs and bovine tibias, to which they initially applied non-destructive bending force to yield the initial Young’s modulus, following which they immersed these samples into different fixation fluids for 6 months. They report that the Young's modulus was significantly lowered in human Thiel specimens when compared to formalin and fresh-frozen samples (6).

To date, there have been no published studies investigating the mechanical characteristics of whole bones, specifically metatarsals. Being major osseous components of the forefoot, the function of metatarsals during gait is of such importance that it is likely that in the future, these will be applied to the study of biomechanical testing of feet, for example in cadaveric gait simulators. Hence this study aimed to compare the mechanical characteristics of Thiel embalmed metatarsals to their fresh-frozen counterparts.

## 2. Materials and Methods

The 1st and 5th metatarsal bones were harvested from three cadavers which had one foot amputated and fresh frozen before the cadaver was embalmed through infusion of Thiel solution through the femoral artery (5). This permitted the availability of 3 sets of bones, with each set being composed of the two Thiel embalmed metatarsals and two fresh-frozen metatarsals from the contralateral foot of the same cadaver, in order to be able to directly compare the bones to each other.

Each metatarsal was mounted on a Testometric (Lincoln, United Kingdom) M350-20CT materials testing device in order for a 3 point bending test to be performed. The two structures which supported the sample were 46mm apart, while a central actuator applied a force exactly in the middle, until fracture of the bone occurred, which caused immediate termination of testing (Figure 1).

*Figure 1: Test setup of the 3-point bending tests*

From the data recorded, fracture force was directly derived as the maximum of the force/deflection graph. Moreover, the total area below the force/ deflection graph and the area until fracture were also calculated to quantify the total energy absorbed by each sample and energy to failure respectively. Paired samples t-test was used to assess the statistical significance of differences between fresh frozen and Thiel embalmed samples.

## 3. Results

The bones from three cadavers (two female, one male, average age 84years) were harvested. Fracture force was lower for all Thiel embalmed samples compared to their fresh frozen counterparts (Figure 2). More specifically in the case of 5th metatarsal average fracture force (±STDEV) for Thiel embalmed and fresh frozen samples was equal to 305N (±241N) and 539 (±232N) respectively. Similarly average (±STDEV) fracture force for Thiel embalmed and fresh frozen 1st metatarsals was equal to 614N (±192N) and 694 (±273N) respectively. Paired samples t-test indicated that the aforementioned difference was also statistically significant in the case of 5th metatarsal (p=0.003, two-tailed) but not in the case of 1st metatarsal (p=0.3, two-tailed).

Thiel embalmed 5th metatarsals had lower total average energy and average fracture energy compared to their fresh frozen counterparts. Similarly in the case of 1st metatarsals average total energy was lower in Thiel embalmed samples compared to fresh frozen but average fracture energy was higher. However paired samples t-test indicated that none of the aforementioned differences in energy was statistically significant (Figure 2).

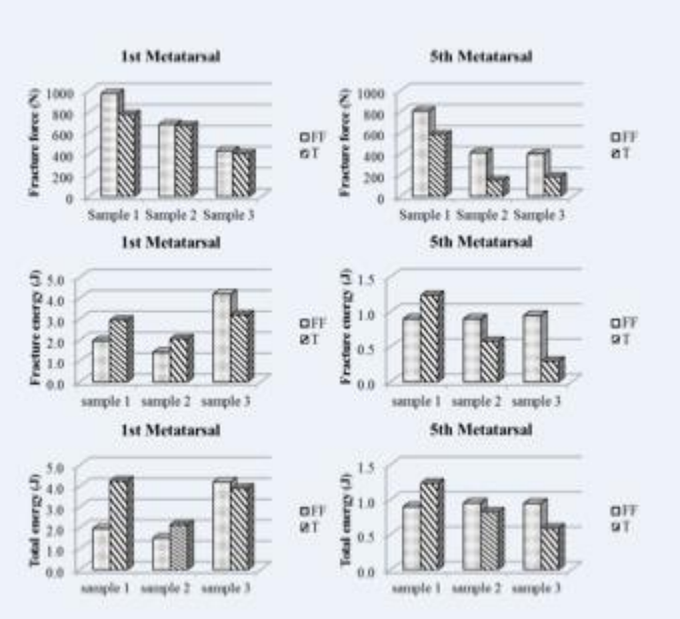

*Figure 2: Comparison of results for Thiel embalmed (T) and fresh frozen (FF) samples. Fracture force, fracture energy and total energy for all three pairs of samples are shown in the first, second and third row respectively for 1st and 5th metatarsals (first and second column respectively).*

## 4. Discussion

The comparison of mechanical properties of the whole bone between Thiel and fresh frozen metatarsals described in this study is the first of kind. The only other reported study on the effect of Thiel embalming on the mechanical characteristics of bone compared cylindrical specimens of bone, which underwent testing twice(6). This opens up the possibility that the bone could already have been weakened after the first testing procedure and prior to testing once Thiel embalmed.

In addition, to the authors' knowledge, this is the first time that bones from the same cadaver were compared to each other in order for the samples to be as similar as possible, and without having to apply force to the sample prior to embalming for fear of weakening the bone. Furthermore, in our study, the bones were embalmed as per normal embalming process, i.e. in exactly the same method as would be used when embalming a cadaver, and not immersed in embalming fluid as per above study (6).

This study approached the handling of data differently from existing studies, with ultimate fracture force, energy to fracture and total energy absorbed being calculated in preference over the traditional stress-strain curve to yield Young's Modulus. Calculating these latter parameters would present significant challenges owing to the fact that a bone is not completely solid, since it is composed of an outer layer of compact bone filled with cancellous material (7). Thus, if modelled, a bone would be represented as a cylindrical object with walls that are as thick as the compact bone, which would make exact measurement difficult. This would be further complicated since the metatarsal is not of uniform thickness.

The results of this study indicate that Thiel embalmed bones are weaker than fresh-frozen ones. Although using different parameters, and different bone samples, our results are comparable to Unger et al. (6).

This type of embalming has opened new possibilities for the utilization of cadaveric material that did not need to be disposed of in a short period of time because of decay. Now, however, it is clear that Thiel embalmed bones, whilst looking exactly like freshly-harvested bone (8), should not be utilized in situations where great strength is required, such as a number of orthopaedic surgical procedures, that would afterwards be tested for strength. Rather, it is also clear that these type of bones should only be utilized for the study of anatomy or for comparative studies where applying clinically relevant forces is not of paramount importance. It is, however, hoped that this study encourages the further development of this embalming technique, until a method of embalming which does not affect the mechanical characteristics of bone is determined.

## 5. Conclusion

Thiel embalmed metatarsals are significantly weaker than fresh-frozen metatarsals, with lower forces required to fracture them. It is thus recommended that these bones should be utilized only for anatomic teaching and not for those biomechanical testing scenarios where clinically relevant forces are to be administered.

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