Printed Three-Dimensional Computerized Tomography Scanned Ankle Fractures as an Educational Instrument.

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Statement of Purpose and Literature Review

Ankle injuries are one of the leading causes of musculoskeletal emergency department visits in the US. According to a contemporary study published in the The Journal of Foot and Ankle Surgery® utilizing the National Trauma Data Bank, an average of 56186 ankle fractures occurred annually between 2007 and 2011 [1]. As such, the evaluation of and treatment protocols for ankle fractures represents an important aspect of the education of podiatric medical students. And although significant technological advances have occurred within nearly all aspects of medicine with respect to patient diagnosis and treatment, the educational tools utilized by medical schools have remained relatively stagnant. Specific to lower extremity traumatology education, many students primarily rely on two-dimensional (2D) representations to visualize and comprehend three-dimensional (3D) pathology. However, the 3D presentation of information has been increasingly utilized in some other areas of medical education and health care [2-5]. In fact and as an example, the National Institute of Health has created the NIH 3D print exchange in hopes of formulating new educational models for medical students and providing information to patients [6].

The objective of this investigation was to examine the feasibility and satisfaction of using 3D printed bone models representative of the Lauge-Hansen classification with a group of third year podiatric medical students enrolled in a foot and ankle traumatology course.

Methodology

Model Preparation

A previous IRB approved protocol evaluating a series of computed tomography (CT) scans of ankle fractures was amended and subsequently approved to include identification and extraction of rotational ankle fractures representative of the Lauge-Hansen classification. Images were initially identified by one study author (TH) and then approved by the senior author (AJM). The selected 3D reconstructed images were then uploaded onto a computer disk (CD) free of all protected patient information by our institution's Department of Radiology.

Next, another study author (KPP) utilized InVesalius 3.0 software (Centro de Tecnologia da Informação Renato Archer, Brazil) to extract Digital Imaging and Communications in Medicine (DICOM) data from the CDs and convert it to stereolithography (STL) format. The STL data was then further imported into MeshLab 2016 software (Visual Computing Lab, Istituto di Scienza e Tecnologie dell'Informazione, Italy) where it underwent 3D rendering and editing. This editing typically consisted of removal of the overlying casting material and bones distal to the ankle joint. Editing also allowed for enhancement of image resolution and the removal of any residual scatter from the original render. Finally, in order to ensure intrinsic stability of the models, 123D design software (Autodesk, San Rafael, California, USA) was used connect all models at the proximal tibia-fibula junction, and if deemed necessary for model stability, bones that were not connected by the intrinsic properties of the fracture characteristics were connected as well.

This finalized data was then exported and saved to a password protected universal serial bus (USB) in the STL format. A Uprint SE Plus printer (Stratasys Worldwide, Eden Prairie, Minnesota, USA) available for hire at our institution's medical library was used for printing. All models were printed with acrylonitrile butadiene styrene plastic in ivory color (See Figures). Models were approximately 20cm high and could be durably handled.

Model Integration

The models were subsequently integrated into Temple University School of Podiatric Medicine's traumatology course curriculum. This was in the form of a hands-on workshop where students could visualize and handle the models in conjunction with case report packets detailing the clinical history and perioperative plain film radiographs of the specific case (See Figures). Models were also additionally available to the students for extracurricular studying.

Following completion of the workshop, students completed a brief survey utilizing a 9-point Likert scale measuring their level of satisfaction with the models with respect to their educational value. And following completion of the course, the final examination questions relating to ankle fractures and ankle fracture classification were extracted. The mean score of these questions was compared to the mean score of these questions from the previous year where no such models were available. An unpaired student t-test was utilized for this comparison.

Results

Models were successfully created and implemented into the curriculum as planned. The survey response rate of the class was 97.8% (89/91), and survey results are displayed in the following table.

Survey Statement Question (1 Extremely inappropriate, 3, 5, 7, 9 Extremely appropriate)	Mean ± Standard Deviation (Range) of Survey Responses
The 3D bone models were an effective supplement to my understanding of the Lauge-Hansen ankle fracture classification.	**8.51 ± 0.74 (7-9)**
It was easier to understand the Lauge-Hansen ankle fracture classification with the use of 3D bone models as opposed to only using two-dimensional figures and radiographs.	**8.55 ± 0.69 (7-9)**
I am likely to spend additional time outside of class studying with the 3D bone models to better understand ankle fractures.	**7.37 ± 1.72 (2-9)**
I would recommend incorporation of the 3D bone models into the traumatology curriculum for future classes.	**8.70 ± 0.59 (6-9)**

A separate workshop was held for a representative sample of the 4th year class who had already completed and passed their traumatology course (n=11). All (100.0%) of these 4th year students recommended incorporation of the 3D bone models into the traumatology curriculum for future classes, and all (100.0%) of these 4th year students expressed that they wished they had had the 3D bone models available when they were initially learning the classification system.

A total of 11 questions on the final examination for the traumatology course were specifically related to rotational ankle fracture diagnosis, classification and treatment. The mean score on this subset of questions for the course involving the 3D bone models was 84%, and for the same group of questions from the previous year's course without models was 76%. This apparent improvement was observed despite the fact that overall course grades between the two years were similar (82% vs. 80%, respectfully).

Discussion

As with any scientific investigation, critical readers are encouraged to review the study design and specific results in order to reach their own conclusions, while the following represents our conclusions based on the specific results. As scientists, we also never consider data to be definitive, but do think that these results are worthy of some attention and future investigation.

-**First**, this investigation demonstrated the feasibility of creating three-dimensional educational tools as part of a podiatric medical education curriculum.

We were able to create durable models representative of the Lauge-Hansen classification system from the CT scans of actual patients with rotational ankle fractures. It was so successful that we have already begun the process to expand these results and create models representative of Lisfranc and calcaneal fracture classifications as well.

We also found the models to be effectively durable and able to withstand clamping, drilling and sawing. This has made us consider utilizing similar models for pre-operative planning and surgical skills workshops for students, residents and surgeons.

-**Second**, this investigation demonstrated high levels of student satisfaction with the implementation of 3D technology. All students indicated that the models were an effective supplement to their education and recommended continued implementation of the workshop within the curriculum. Most students indicated that they were likely to spend time outside of class working with the models as they were studying the Lauge-Hansen classification system.

In conclusion, the results of this investigation demonstrate that 3D technology within podiatric medical and surgical education is feasible with high levels of student satisfaction.

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