



Contents lists available at ScienceDirect

The Journal of Foot & Ankle Surgery

journal homepage: www.jfas.org

Original Research

Printed 3-Dimensional Computed Tomography Scanned Ankle Fractures as an Educational Instrument

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ARTICLE INFO

Level of Clinical Evidence: 5

Keywords:

fibula fracture
 medical student education
 rotational ankle fracture
 student satisfaction
 surgical workshop
 syndesmosis
 technology

ABSTRACT

The evaluation of and treatment protocols for ankle fractures represents an important aspect of the education of podiatric medical students. The objective of this investigation was to examine the feasibility of and student satisfaction with using 3-dimensional (3D) printed bone models representative of the Lauge-Hansen classification. The computed tomography scans of subjects with actual rotational ankle fractures representative of the Lauge-Hansen classification were identified and extracted into a format compatible with a 3D printer. The models were approximately 20 cm in height and made of acrylonitrile butadiene styrene plastic in ivory color. These were subsequently implemented into the curriculum of a traumatology course with third year podiatric medical students in the form of a hands-on workshop. Students expressed high levels of satisfaction with the use of these models, and most recommended their continued implementation within the curriculum. The results of this investigation indicate that 3D technology within podiatric medical education is feasible with high levels of student satisfaction.

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Ankle injuries are one of the leading causes of musculoskeletal emergency department visits in the United States. According to a contemporary study using the National Trauma Data Bank, an average of 56,186 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 treatment, the educational tools used by medical schools have remained relatively stagnant. Specific to lower extremity traumatology education, many students primarily rely on 2-dimensional representations to visualize and comprehend 3-dimensional (3D) pathology; however, the 3D presentation of information has been increasingly used in some other areas of medical education and health care. In fact and as an example, the National Institutes of Health has created the NIH 3D print exchange in hopes of formulating new educational models for medical students and providing information to patients (2).

Financial Disclosure: A portion of this investigation was funded by a 2017 American College of Foot and Ankle Surgeons scientific educational grant.

Conflict of Interest: A.J.M. serves as a *JFAS* section editor.

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Although a few studies have demonstrated that interactive 3D models are more effective teaching instruments than textbooks alone (3–6), we are unaware of any investigation into the effect of 3D models on the education of podiatric medical students learning about rotational ankle fractures. The objective of this investigation was therefore to examine the feasibility of and student satisfaction with using 3D printed bone models representative of the Lauge-Hansen classification.

Materials and Methods

Model Preparation

A previous institutional review board–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 (7). Images were initially identified by 1 study author (T.H.) and then approved by the senior author (A.J.M.). The selected CT images were then uploaded onto a computer disk free of all protected patient information by our institution's Department of Radiology.

Next, another study author (K.P.P.) used InVesalius 3.0 software (Centro de Tecnologia da Informação Renato Archer, Brazil) to extract Digital Imaging and Communications in Medicine data from the disks and convert that data to stereolithography (STL) format. The STL data were 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



Fig. 1. Three-dimensional (3D) bone models representative of the Lauge-Hansen rotational ankle fracture classification system. The objective of this investigation was to examine the feasibility of and student satisfaction with using 3D printed bone models representative of the Lauge-Hansen classification. From the computed tomography scans of subjects with actual rotational ankle fractures, we were able to create durable models that were implemented into the traumatology curriculum for third-year podiatric medical students.

scatter from the original render. Finally, to ensure intrinsic stability of the models, 123D design software (Autodesk, San Rafael, CA) 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 were then exported and saved to a password-protected universal serial bus in the STL format. A Uprint SE Plus printer (Stratasys Worldwide, Eden Prairie, MN) 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 (Fig. 1). Models were approximately 20 cm high and could be durably handled.

Model Integration

The models were subsequently integrated into Temple University School of Podiatric Medicine's class of 2019 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 (Fig. 2). In previous years, no hands-on workshop was available and student education with respect to rotational ankle fractures was solely through lectures. Once created, models were also additionally available to the students for extracurricular study (Fig. 3).

Outcomes

Following completion of the workshop, students completed a 4-question survey measuring their level of satisfaction with respect to the educational value of the models. This survey consisted of a 9-point Likert scale (Fig. 4) of the following statements:

- "The 3D bone models were an effective supplement to my understanding of the Lauge-Hansen ankle fracture classification."
- "It was easier to understand the Lauge-Hansen ankle fracture classification with the use of 3D bone models as opposed to only using 2-dimensional figures and radiographs."
- "I am likely to spend more time outside of class studying with the 3D bone models to better understand ankle fractures."
- "I would recommend incorporation of the 3D bone models into the traumatology curriculum for future classes."

Results

The 3D bone models were successfully created and implemented into the traumatology curriculum as planned. A total of 89 (97.8%) of 91



Fig. 2. Model integration into the traumatology curriculum. The models were implemented into a hands-on workshop reviewing the Lauge-Hansen rotation ankle fracture classification system with accompanying case workups including the perioperative imaging.



Fig. 3. Extracurricular study with the models. The models were made available for the students for extracurricular study.

students returned the survey. The mean ± standard deviation (range) survey responses were as follows (Table):

- “The 3D bone models were an effective supplement to my understanding of the Lauge-Hansen ankle fracture classification: 8.51 ± 0.74 (range 7 to 9).”
- “It was easier to understand the Lauge-Hansen ankle fracture classification with the use of 3D bone models as opposed to only using 2-dimensional figures and radiographs: 8.55 ± 0.69 (range 7 to 9).”
- “I am likely to spend more time outside of class studying with the 3D bone models to better understand ankle fractures: 7.37 ± 1.72 (range 2 to 9).”
- “I would recommend incorporation of the 3D bone models into the traumatology curriculum for future classes: 8.70 ± 0.59 (range 6 to 9).”

Discussion

First, this investigation demonstrated the feasibility of creating 3D educational tools as part of a podiatric medical education curriculum. We considered our results to demonstrate feasibility as the models were successfully created and implemented into the curriculum. We subjectively found the models to be durable and able to withstand clamping, drilling, and sawing. This has made us consider constructing and using similar models for preoperative planning

and surgical skills workshops for students, residents, and surgeons in the future. We also intend to expand on this concept through the creation of models representative of other lower extremity fracture classifications as well.

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

All investigations have limitations, and this study had several important ones to consider. First, information was collected from a limited

Table
Results of the primary outcome measure

| Survey Statement Questions (n = 89 Respondents) | Mean ± SD (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 (range 7 to 9) |
| It was easier to understand the Lauge-Hansen ankle fracture classification with the use of 3D bone models as opposed to only using 2-dimensional figures and radiographs. | 8.55 ± 0.69 (range 7 to 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 (range 2 to 9) |
| I would recommend incorporation of the 3D bone models into the traumatology curriculum for future classes. | 8.70 ± 0.59 (range 6 to 9) |

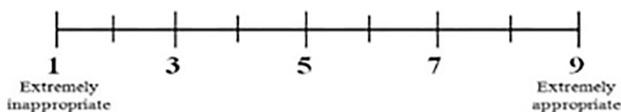


Fig. 4. A 9-point modified Likert scale. As a primary outcome, student satisfaction with the models was measured using a survey consisting of a 9-point modified Likert scale.

amount of students from a single school of podiatric medicine; therefore, these results might not be representative of other students or schools. Second, although the satisfaction surveys were completed in an anonymous manner, students might have felt compelled to report higher levels of satisfaction with the workshop because they were yet to receive a final grade for the course. Third, the specific survey we used was not a recognized or validated outcome measure, and we made no attempt to provide reliability data of its use. And finally, we cannot be sure that the high levels of satisfaction we observed were completely from the use of models within the workshop or whether they simply served as a surrogate to the workshop itself.

In conclusion, the results of this investigation demonstrate that 3D technology within podiatric medical education is feasible with high levels of student satisfaction. It is our hope that this investigation leads to other advances in the technology used to teach podiatric medical students.

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