The addition of 3D printed models to enhance the teaching and learning of bone spatial anatomy and fractures for undergraduate students: a randomized controlled study

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Background: Whether or not the addition of 3D (three-dimension) printed models can enhance the teaching and learning environment for undergraduate students in regard to bone spatial anatomy is still unknown. In this study, we investigated the use of 3D printed models versus radiographic images as a technique for the education of medical students about bone spatial anatomy and fractures.

Methods: The computed tomography (CT) data from four patients, each with a different fracture type (one spinal fracture, one pelvic fracture, one upper limb fracture, and one lower limb fracture), were obtained, and 3D models of the fractures were printed. A total of 90 medical students were enrolled in the study and randomly divided into two groups as follows: a traditional radiographic image group (presented by PowerPoint) and a 3D printed model group (combined PowerPoint and 3D models). Each student answered 5 questions about one type of fracture and completed a visual analog scale of satisfaction (0–10 points).

Results: No significant differences were found in the upper limb or lower limb test scores between the 3D printed model group and the traditional radiographic image group; however, the scores on the pelvis and spine test for the traditional radiographic image group were significantly lower than the scores for the 3D printed model group (P=0.000). No significant differences were found in the test-taking times for the upper limb or lower limb (P=0.603 and P=0.746, respectively) between the two groups; however, the test-taking times for the pelvis and spine in the traditional radiographic image group were significantly longer than those of the 3D printed model group (P=0.000 and P=0.002, respectively).

Conclusions: The 3D printed model may improve medical students' understanding of bone spatial anatomy and fractures in some anatomically complex sites.

Keywords: Bone fracture; 3D printing; medical education; medical teaching; randomized controlled study

Submitted Jun 04, 2018. Accepted for publication Sep 21, 2018.
doi: 10.21037/atm.2018.09.59
View this article at: http://dx.doi.org/10.21037/atm.2018.09.59

Introduction

Knowledge of skeletal anatomy and bone fractures is a fundamental educational component for every undergraduate medical student. In traditional medical education, cadaveric specimens and radiographic images are used for education and research (1-3) as well as for audio-visual resources. However, cadaveric specimens are only used in a normal skeletal anatomy course.

To teach the morphological changes that are associated with bone fracture or other medical conditions, 3D reconstructed images on PowerPoint and PACS (picture archiving and communication system) are currently the most widely used options (4). There have been ethical issues associated with the acquisition of cadavers, and in many countries, body donation is low (5-8). These circumstances, along with the expense associated with storing the cadaveric specimens, have led to limited use of cadavers (9).

Since 2000, the 3D printing technique has developed rapidly and is widely used in the manufacturing industry (10,11). The 3D printing technique has now been introduced into the medical and biomedical fields (12-15) and has potential value in clinical practice (16-19). 3D printed bone models are promisingly accurate in morphology (20), including the morphology of bone fractures. The price of 3D printing technology has now reached a reasonable cost level (13,21), and it has been introduced to be used for surgical planning (22) and medical teaching (23-25).

Whether the addition of 3D printed models enhances the teaching and learning of bone spatial anatomy and fractures by undergraduate students is still unknown. In this study, we conducted a randomized controlled trial comparing 3D printed models versus radiographic images in the education of undergraduate medical students on bone fractures.

Methods

This study was performed according to the Declaration of Helsinki principles and was approved by the Institutional Review Board (IRB) of The Second Affiliated Hospital and Yuying Children's Hospital of Wenzhou Medical University (Approval No. 2017-01). Written informed consent was obtained from all participants, and the process was performed according to the approved guidelines.

The original CT data in DICOM format from four patients, each with a different fracture type (one spinal fracture, one pelvic fracture, one upper limb fracture, and one lower limb fracture), were obtained from the Star PACS system (INFINITT, Seoul, South Korea) of our hospital (3). All the data were imported into the software Mimics 16.0 (Materialise, Belgium). The threshold value was set at "Bone (CT)" to reconstruct the 3D images. After the 3D digital images were calculated and reconstructed (26), the data were then saved in STL format and imported into the 3D printer (Liantai, Shanghai) (27). All of the fractures described above were transformed into 3D printed models and preserved for education.

A total of 90 medical students from Wenzhou Medical University were enrolled in this study in March 2017. All students completed the gross anatomy and regional normal anatomy courses. The scores achieved on the final exam for both gross anatomy and local normal anatomy courses were collected and compared to assess the participants' baseline knowledge of human body anatomy. Then, all of the students were randomly divided into two groups as follows: a traditional radiographic image group (45 students) and a 3D printed model group (45 students) (*Figure 1*).

For the traditional radiographic image group, the lecture was presented using PowerPoint and included normal anatomy, the definition of fractures, and the presentation of the fractures on X-ray and CT. Before the presentation to the 3D printed model group, students were paired, and each pair received four different fracture models (one spinal fracture, one pelvic fracture, one upper limb fracture, and one lower limb fracture). Students in this group learned from a combination of PowerPoint and the visible 3D printed models.

Following the presentation to each group, each student answered 5 questions for each type of fracture. Students received two points for each question answered correctly, and a total of 20 questions were posed for the four different site fractures (File S1). Additionally, students completed questions related to a visual analog scale of satisfaction (0–10 points) representing the students' comprehensive satisfaction with the class from any aspect (0 is very poor, 10 is very good). The results of the test and the test-taking time were assessed and recorded.

Statistical analysis

SPSS software (version 17.0, SPSS Inc., Chicago, IL, USA) was used to analyze the data. The data are described using mean and standard deviation (SD). The *t*-test was used to compare the two groups, and the level of significance was set at $P<0.05$.

Results

There were 29 males and 16 females in the traditional radiographic image group and 27 males and 18 females in the 3D printed model group. No significant differences were found in final exam scores for the gross anatomy or the regional normal anatomy courses between the traditional radiographic image group and the 3D printed model group,

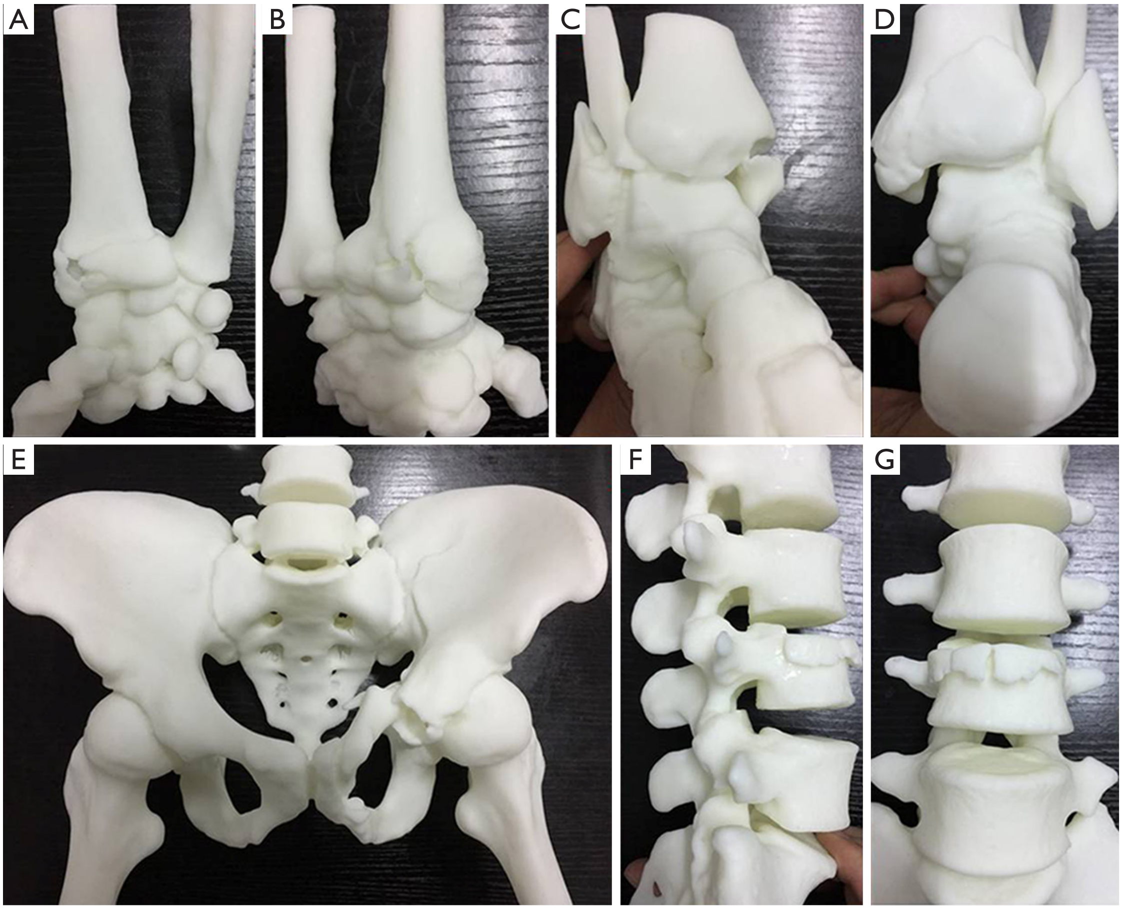

Figure 1 The photos of the 3D printed models for education are shown. (A,B) The photo of an upper limb fracture; (C,D) the photo of a lower limb fracture; (E) the photo of a pelvic fracture; (F,G) the photo of spinal fracture.

with P=0.498 for the gross anatomy course and P=0.574 for the regional anatomy course. The details of the summary scores are shown in *Table 1*. When comparing the scores between the two groups, no significant differences were observed in the scores for the upper limb test or the lower limb test (P=0.500 and P=0.563, respectively); however, the scores for the pelvis and the spine tests for the traditional radiographic image group were significantly lower than those for the 3D printed model group (P<0.001).

The details of the test-taking times are shown in *Table 2*. When comparing the test-taking times between the two groups, no significant differences were observed in the test-taking times for the upper limb or lower limb (P=0.603 and P=0.746, respectively); however, the test-taking times for the pelvis and the spine for the traditional radiographic image group were significantly longer than the test-taking times for the 3D printed model group (P<0.001 and P=0.002, respectively).

The visual analog scale of satisfaction mean score was 7.49±1.38 for the 3D printed model group and 5.80±1.30 for the traditional radiographic image group, with P<0.001 (*Table 3*).

Discussion

The 3D printing technique can provide a 3D printed model of almost any shape from a 3D digital model or other electronic data source (10,27). It can also provide an accurate model (20,28) for use in anatomy education (29), which may be especially useful in some countries that lack cadaver donations (5,7). Further, most cadaveric specimens have normal anatomy and are not useful for learning about fractures.

For the traditional radiographic image group, a PowerPoint of X-ray and CT images and 3D anatomical

Table 1 The comparison of summary scores between the two groups

Sites	Traditional radiographic image group	3D printed model group	T	P
Upper limb	7.24±1.61	7.47±1.50	−0.677	0.500
Lower limb	7.20±1.56	7.38±1.34	−0.588	0.563
Pelvis	4.93±1.79	6.89±1.39	−5.798	<0.001
Spine	4.76±1.61	6.93±1.51	−6.607	<0.001

Table 2 The comparison of test-taking times (seconds) between the two groups

Sites	Traditional radiographic image group	3D printed model group	T	P
Upper limb	193.2±40.2	189.3±29.5	0.523	0.603
Lower limb	190.8±42.6	188.2±31.1	0.325	0.746
Pelvis	295.8±49.4	246.4±38.9	5.269	<0.001
Spine	270.3±54.3	237.9±42.9	3.136	0.002

Table 3 The comparison of visual analog scale of satisfaction scores between the two groups

Parameter	Traditional radiographic image group	3D printed model group	T	P
Visual analog scale of satisfaction	5.80±1.30	7.49±1.38	−5.973	<0.001

software were used for the medical education. The 3D printed technique may help us to improve medical education. Langridge *et al.* (30) performed a systematic review of the use of 3D printing in surgical training and assessment. They found the following: previous studies had significant heterogeneity, which precluded any meta-analysis; most studies looked at use of 3D printing in the areas of neurosurgery and otorhinolaryngology; and 3D printing showed better outcomes in most of these studies. For anatomy education, there had been three randomized controlled studies: one about the hepatic segments (31), one about external cardiac anatomy (25), and one about spinal fractures (32).

In a study by Li *et al.* (32), 3D printed models significantly improved the identification of spinal fractures by medical students; however, only spinal fractures were studied. In the current study, the sites of bone anatomy and fractures included the spine, pelvis, upper limbs and lower limbs. We found that the summary scores were similar between the two groups for the upper limb and lower limb tests, and the scores were significantly higher in the 3D printed model group than in the traditional radiographic image group for the spine and pelvis tests. Compared to the study by Li *et al.* (32), our present findings suggest that 3D printed models may be helpful for understanding bone anatomy and fractures of the pelvis and spine, but not of the upper and lower limbs.

One factor contributing to the different test results obtained in this study may be that the anatomy of the pelvis and spine is more complex than limb anatomy, thus making it harder for students to understand the spatial anatomy of the pelvis and spine compared to the upper and lower limbs. The mean scores of the pelvis and spine tests were less than 5 among the traditional radiographic image group, whereas students in the 3D printed model group demonstrated higher scores by 1.96 and 2.17 points on the pelvis and spine tests, respectively. The mean scores of the upper and lower limb tests were more than 7 among both groups. Students did not demonstrate a significant benefit from the 3D printed models, suggesting that it is easier to understand the spatial anatomy of upper and lower limbs, and the 3D printed models were not necessary.

Interestingly, we found that the students who had lower test-taking times had higher summary scores, which confirmed that the students in the 3D printed model group benefitted from greater understanding of fractures of the pelvis and spine and that they answered questions at a faster rate.

The mean score on the visual analog scale of satisfaction for the students in the 3D printed model group was 1.69 points (16.9%) higher than the mean score of the traditional radiographic image group (P<0.001), suggesting the 3D printed model method of education improved student satisfaction.

One benefit of using a 3D printed model is that the 3D printed model does not have a significant cost (33). The price of the 3D printing material is different across countries and brands (34,35). In this study, the weight of the spine, the upper limb and the lower limb models ranged from 40 to 70 grams, and the pelvis model weighed approximately 600 grams. The cost of the print material was approximately \$0.15 per gram. Therefore, the cost of the spine, the upper limb and the lower limb models was approximately \$6–\$10.50, and the pelvis model cost approximately \$90, which does not include the depreciation of the 3D printer. The printed model can be used multiple times and preserved for a long period of time.

Although it is easier to obtain images of bodies for 3D printing than to obtain a whole body for donation (36), the ethics of 3D printing copies of bodies donated for medical education and research should be considered (37). Informed consent needs to be obtained and protection of individual donor information needs to be ensured.

There were some limitations to this study and to the 3D printing techniques. First, the 3D printed models in this study did not include soft tissue, such as nerves, vessels and muscles around the bone. Second, the 3D printing process takes time, from hours to days, depending on the volume of the printed models. The time requirement may be reduced with further development of 3D print technology. Third, the sample size of this study was not large, and some potential bias or heterogeneity may have influenced the results. We used a randomized method to avoid the potential bias as much possible.

Conclusions

The 3D printed model may improve medical students' understanding of bone spatial anatomy and fractures in some anatomically complex sites and may improve student satisfaction in medical education.

Acknowledgements

Funding: This work was supported by the Higher Education Teaching Reform Project of Wenzhou Medical University (YBJG201826), Wenzhou Municipal Science and Technology Bureau (Y20170389), Wenzhou Leading Talent Innovative Project (RX2016004), Zhejiang Provincial Medical Technology Foundation of China (2018KY129), and the National Natural Science Foundation of China (81501933).

Footnote

Conflicts of Interest: The authors have no conflicts of interest to declare.

Ethical Statement: This study was performed according to the Declaration of Helsinki principles and was approved by the Institutional Review Board (IRB) of The Second Affiliated Hospital and Yuying Children's Hospital of Wenzhou Medical University (Approval No. 2017-01). Written informed consent was obtained from all participants, and the process was performed according to the approved guidelines.

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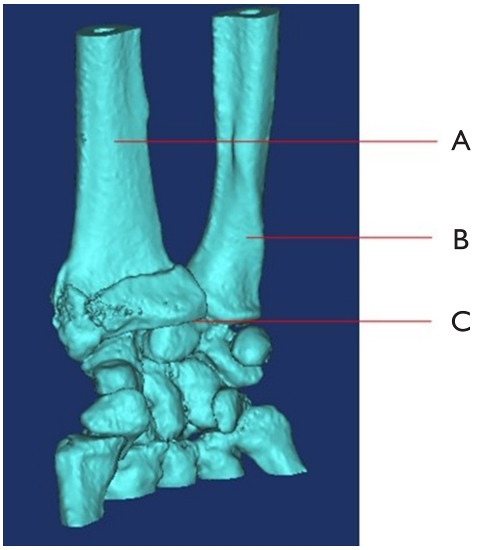
Cite this article as: Wu AM, Wang K, Wang JS, Chen CH, Yang XD, Ni WF, Hu YZ. The addition of 3D printed models to enhance the teaching and learning of bone spatial anatomy and fractures for undergraduate students: a randomized controlled study. Ann Transl Med 2018;6(20):403. doi: 10.21037/atm.2018.09.59

Supplementary

The questions

Part One



1.What's name of bone that marked as "A"
   a. Ulna
   b. Radius
   c. Fibula
   d. Tibia

2. What's name of bone that marked as "B"
   a. Ulna
   b. Radius
   c. Fibula
   d. Tibia

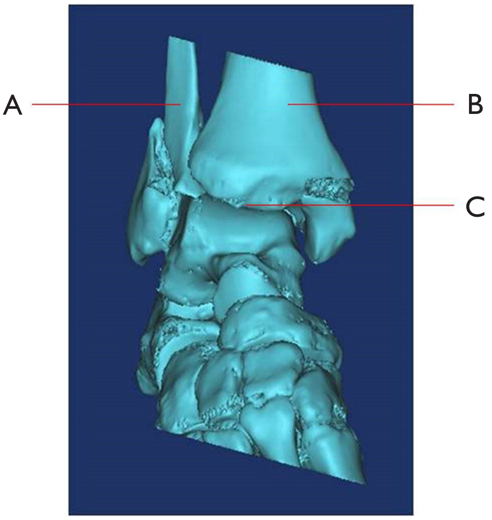
3. Which bone involves fracture?
   a. None of "A" and "B"
   b. Both of "A" and "B"
   c. Only "A"
   d. Only "B"

4. What's name of the joint that marked as "C"?
   a. Knee Joint
   b. Elbow joint
   c. Ankle joint
   d. Wrist joint

5. What's the name of bone that locates at proximal end of "A" and "B"?
   a. Femur
   b. Patella

c. Humerus
d. Scapula

Part Two



1. What's name of bone that marked as "A"
   a. Ulna
   b. Radius
   c. Fibula
   d. Tibia

2. What's name of bone that marked as "B"
   a. Ulna
   b. Radius
   c. Fibula
   d. Tibia

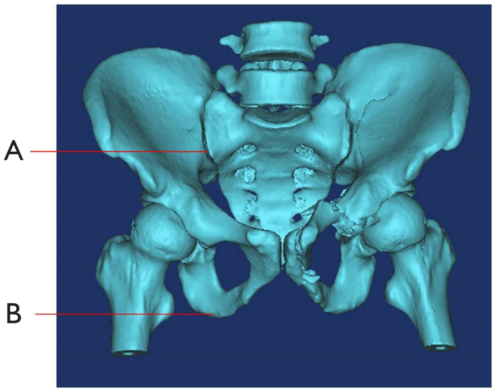
3. Which bone involves fracture?
   a. None of "A" and "B"
   b. Both of "A" and "B"
   c. Only "A"
   d. Only "B"

4. What's name of the joint that marked as "C"?
   a. Knee Joint
   b. Elbow joint
   c. Ankle joint
   d. Wrist joint

5. What's the name of bone that locates at distal end of "A" and "B"?
   a. Calcaneus
   b. Talus

c. Cuboid bone
d. Navicular bone

Part Three



1. What's name of bone that marked as "B"
   a. Sacrum
   b. Pubis
   c. Ilium
   d. Ischium

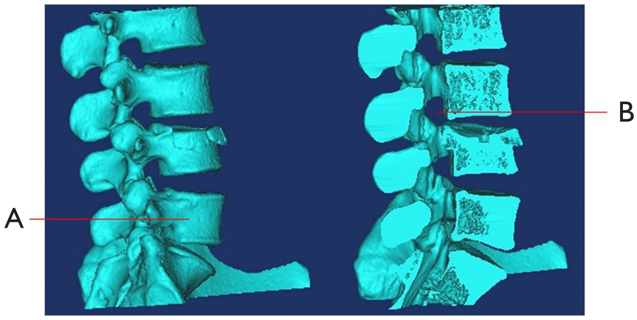
2. What's name of the joint/symphysis that marked as "A"?
   a. Sacroiliac joint
   b. Hip joint
   c. Pubic symphysis
   d. Sacrococcygeal symphysis

3. Which bone involves fracture?
   a. Only the bone of Pubis and Ischium.
   b. Only the bone of pubis, ischium and sacrum
   c. Only the bone of pubis, ischium and ilium.
   d. All the bone of pubis, ischium, sacrum and ilium.

4. Did the fracture involve the following joints?
   a. None of "Sacroiliac joint" and "Hip joint".
   b. Both of "Sacroiliac joint" and "Hip joint".
   c. Only "Sacroiliac joint"
   d. Only "Hip joint".

5. Did the fracture involve the pubic tubercle?
   a. Yes
   b. No

Part Four



1. what's name of bone that marked as "A"
   a. Spinous process
   b. Vertebral body
   c. Vertebral disc
   d. Sacrum

2. What's name of the site marked as "B"?
   a. Transverse foramen
   b. Intervertebral space
   c. Pedicle
   d. Intervertebral foramen

3. Which vertebrae does the fracture involve?
   a. L3
   b. L4
   c. L5
   d. Both L4 and L5

4. Which following construct does the fracture involve?
   a. Vertebral body
   b. Vertebral body and pedicle
   c. Vertebral body, pedicle and lamina
   d. Vertebral body, pedicle, lamina and spinous Process

5. Which following construct impacted by the fracture?
   a. Intervertebral space
   b. Intervertebral space and vertebral foramen
   c. Intervertebral space, vertebral foramen and intervertebral foramen
   d. None of above.