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The Role of 3D Modeling in Education of Orthopedic Trainees for the Treatment of Foot Deformities

Význam 3D modelování v edukaci mladých ortopedů při léčení deformit nohy

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ABSTRACT

PURPOSE OF THE STUDY

We hypothesized that preoperative planning with 3D modeling of complex foot deformities would be useful for the education of orthopedics and traumatology residents.

MATERIAL AND METHODS

This study is prospectively designed study with a control group. Twenty eight residents (study group) who assisted the surgeons during the interventions and ten senior surgeons (control group) were included in the study. All participants assessed virtual 3D-CT images and videos of the cases before the surgery.

Ten adult cases of foot bone deformities were evaluated. 3D-CT reconstruction was performed and a 3D model of each deformity was created using the hospital's picture archiving and communication system. The completed 3D models were sterilized in hydrogen peroxide and put on the surgical table in a sterile manner.

After surgery, the residents (group I) and surgeons (group II) were questioned regarding their satisfaction with 3D modeling. Responses were structured by a five-point Likert scale (1, strongly disagree; 2, disagree; 3, neither agree nor disagree; 4, agree; and 5, strongly agree).

RESULTS

The surgeons (group II, n = 10) were satisfied with the sterilized 3D models, which they could touch and re-examine on the operating table. The residents (group I, n = 28) were significantly more satisfied than the senior surgeons (p=0.01). The 3D modeling met both the surgeons' and residents' expectations.

DISCUSSION

The survey results for the surgeons (group II) were satisfied with the sterilized 3D models, which they could touch and re-examine on the operating table (question 3). They gave the best scores (mean, 4.8/5) for clarity of the 3D model. On the other hand, they gave the lowest scores (mean 3.1/5) to 3D models due to its contribution in understanding deformity over virtual 3D-CT evaluations (question 2 and 5).

The residents (group I) differed from those for the senior surgeons. Residents gave the highest scores for understanding of the deformity (question 2 and 5) and clarity (question 1). These outcomes may be interpreted to indicate i) that 3D modeling may be used for education, and ii) that younger surgeons are more interested in novel technological developments. Therefore, the outcomes did differ significantly between the senior surgeons and residents (Table 1). These outcomes may be explicated as; 3D modeling of the foot deformities may not be mandatory for the experienced surgeons for understanding the deformity. On the other hand 3D modeling would be useful tools for younger surgeons and for their education.

CONCLUSIONS

3D modeling of foot deformities is more informative than virtual 3D videos. However, with consideration of costs and long processing times, 3D printing may be used optimally for rare deformities. When considering the role of touch sense in surgical learning, 3D modeling gives more detailed and more satisfactory planning than virtual 3D videos. 3D modeling is more useful for young surgeons, and it will be used mainly for education in the future.

Key words: 3D printing, deformity, foot and ankle, simulation.

INTRODUCTION

Three-dimensional (3D) modeling based on 3D computed tomography (CT) reconstruction is being used in orthopedics and traumatology practice. With 3D modeling, anatomical structures can be reconstructed from 3D CT volumes and then reproduced as physical models (Fig. 1), which can then be used for surgical planning and training for patients and trainees. Similarly, 3D printing can be applied to the design of surgical simulations, which provide realistic representations of surgical procedures without the risk of patient harm. This approach is currently used for preoperative plate bending in trauma cases and preoperative planning in the treatment of bone deformities, fractures, and malunions (2, 5, 6, 8, 9, 14). In foot and ankle surgery, preoperative 3D modeling is gaining popularity; not only for rarely seen foot deformities, but also for hallux valgus surgery (14) and or-

Fig. 1. Three-dimensional model of a cavus deformity.

Fig. 2. Three-dimensional model of a skewfoot deformity that was sterilized and put on the table during the operation.

thosis preparation (3). In the literature it is seen that 3D models are also being used for educational purposes (1, 10, 12). Because the inclusion of 3D models in the surgical training programs would integrate the senses of touch and visual data in the learning process.

We hypothesized that preoperative planning with 3D modeling of complex foot deformities would be useful for residents. For this purpose we aimed to compare the satisfaction with 3D videos and printed 3D models both in experienced and unexperienced physician group.

MATERIAL AND METHODS

All clinical procedures performed in this study were in accordance with the ethical standards of the institutional and national research committees and the 1964 Helsinki declaration and its amendments. Informed consent was obtained from all study participants. This article does not report on any animal study performed by any of the authors. The study was approved by the ethics committee of İstanbul Medeniyet Universitesi, Göztepe Training and Research Hospital (no. 2017/0326).

Ten adult cases of foot bone deformity were included in the study. Minimal deformities and deformities treated mainly with soft-tissue procedures were excluded. Twenty-eight residents (3rd and 4th years at the orthopedic training) who assisted the surgeons during the interventions were the main study group. On the other hand, ten surgeons who mainly treated foot–ankle deformities, with more than 5 years of experience each, performed the surgeries. Surgeons were determined as a control group in the study.

The patients' diagnoses were calcaneus fracture malunion ($n = 3$), recurvatum foot deformity due to Charcot neuroarthropathy ($n = 2$), pes cavus ($n = 2$), neglected pes equinovarus deformity ($n = 1$), ankle varus deformity due to syndesmotic osteochondroma ($n = 1$), and congenital skewfoot deformity ($n = 1$).

All patients underwent routine axial, sagittal, and coronal CT examinations of the foot and ankle (Optima CT660; General Electric Healthcare, Tokyo, Japan) with the following parameters: field of view, extremity; interval, 0.625 mm; number of images, 163; total exposure time, 2.99 min. 3D reconstruction was performed and virtual 3D-CT video were shown to all participants (Video). Then 3D model of each deformity was created using the hospital's picture archiving and communication system. Imaging of unrelated bony parts was removed using Horos® software (Annapolis, MD, USA). The models were printed with an Ultimaker Extended-2 Plus 3D printer using 1.75 mm polylactic acid (PLA) filament. The layer height was adjusted to 0.15 mm and the infill rate was adjusted to 80%.

After the bone models were created, both group of participants examined the models and made preoperative planning on them. 3D models were sterilized in hydrogen peroxide and put on the surgical table in a sterile manner (Fig. 2).

After surgery, the surgeons (group I) and residents (group II) were questioned regarding their satisfaction with virtual 3D-CT reconstruction and also with 3D modeling. Responses were structured by a five-point Likert scale (1, strongly disagree; 2, disagree; 3, neither agree nor disagree; 4, agree; and 5, strongly agree). The Table shows the questions asked of the surgeons and the mean response values. Data from the respondent groups were compared statistically using SPSS 21.0 (SPSS, Chicago, IL, USA). P values < 0.05 were considered to be significant. The Mann–Whitney U test was used to compare the responses between groups.

RESULTS

Ten 3D plastic models of foot deformities were printed. The average time to print one foot model was 14.2 (range, 8.4–7.3) hours.

The residents (group I, n = 28) and also the surgeons (group II, n = 10) were satisfied with the sterilized 3D models, which they could touch and re-examine on the operating table. The Table shows mean values for their responses to the questionnaire items. While the 3D modeling met the surgeons' expectations (87%), the residents were more satisfied (96.6%) than the senior surgeons.

Significant difference was observed between the groups in question 2 (3D modeling helped me to understand the deformity better) and question 5 (Although I have had evaluated the 3D-CT, 3D models made me to understand the deformity better). Value of significance was 0.03 and 0.02 respectively.

DISCUSSION

Understanding of rare foot deformities and preoperative planning of their treatments may be challenging for unexperienced surgeons. In this study we aimed to investigate the role of 3D modelling in the education of orthopedics and traumatology residents for the treatment of rare foot deformities. For this purpose satisfaction of the participants were taken into consideration. Since there is no standard evaluation method regarding the comprehension of these different kind of foot deformities we considered to take satisfaction as an educational output.

In this study, 3D printing was used for rare foot deformities, such as skewfoot and neglected pes equinovarus deformities, with which young surgeons usually have limited experience. Deformity correction was planned on the models. In the distal tibia varus deformity case, the widths of the opening osteotomy and required graft were planned preoperatively. For the pes cavus deformities, a calcaneal sliding osteotomy and first metatarsal dorsal closing wedge osteotomy were planned (Fig. 1). Deformity correction was planned for the Charcot neuroarthropathy and calcaneal malunion cases. However, cutting of the 3D models to simulate osteotomy caused the saw to overheat. In the future, this procedure should be attempted with models made of a plastic other than PLA.

The survey results for the surgeons (group II) were satisfied with the sterilized 3D models, which they could touch and re-examine on the operating table (question 3). They gave the best scores (mean, 4.8/5) for clarity of the 3D model. On the other hand, they gave the lowest scores (mean 3.1/5) to 3D models due to its contribution in understanding deformity over virtual 3D-CT evaluations (question 2 and 5).

The residents (group I) differed from those for the senior surgeons. Residents gave the highest scores for understanding of the deformity (question 2 and 5) and clarity (question 1). These outcomes may be interpreted to indicate i) that 3D modeling may be used for education, and ii) that younger surgeons are more interested in novel technological developments. Therefore, the outcomes did differ significantly between the senior surgeons and residents (Table). These outcomes may be explicated as; 3D modeling of the foot deformities may not be mandatory for the experienced surgeons for understanding the deformity. On the other hand 3D modeling would be useful tools for younger surgeons and for their education.

3D printing has increased its' popularity in recent years. Recent publications have described several applications of 3D printing in various subspecialties of orthopedics and traumatology (2, 3, 5, 6, 8, 9, 10, 11, 13, 14). The usage of 3D printing in personalized footwear, orthosis preparation (3) and educational purposes (1, 10, 12) are prevalent industrial areas of this related topic. Most studies have shown that 3D modeling may decrease surgery duration and blood loss (4, 7, 13). Galvez et al. reported that 3D printing satisfied surgeons and patients (7). We also saw that 3D bone models were useful for informing patients about their deformities. The patients were excited and satisfied, but we did not score their responses.

When no tool for the conversion of .dicom to .stl format is available, the processing of CT scans for 3D model printing takes a long time. Because segmentation procedures and adjustment for better modeling still needs advanced experience. Nevertheless, 3D modeling is extremely beneficial in terms of efficacy and usefulness, especially for rare, complex deformities. Our hypothesis was supported for complex foot deformities. Therefore, 3D modeling is likely to become inevitable in the future.

With the support of radiological imaging, preoperative modeling enabled surgical planning and simulation. With the development of 3D printing technology, model production speeds will increase and the costs will decrease. In this way, preoperative planning with 3D-printed models, surgical simulation with preoperative planning, and the use of intraoperative guides may become routine practices in the training of orthopedic residents.

Table 1. The mean responses of the residents and surgeons according to Likert scale

Questions		Mean responses		
		Residents surgeons group I (n = 28) mean ± SD	**Senior surgeons group II (n = 10) mean ± SD**	**p value**
Q1	Is the 3D model clear for the detection of bones, joints and deformity?	4.85 ± 0.35	4.8 ± 0.42	0.807
Q2	The 3D modeling helped me to understand the deformity better.	4.89 ± 0.31	4.1 ± 0.73	0.03
Q3	I am very satisfied with the 3D modeling.	4.71 ± 0.46	4.6 ± 0.51	0.613
Q4	I will recommend the 3D modeling to other specialists.	4.82 ± 0.39	4.6 ± 0.51	0.317
Q5	Although I have had evaluated the 3D-CT, 3D models made me to understand the deformity better.	4.89 ± 0.31	3.1 ± 0.82	0.01
Independent samples Mann-Whitney U test				
Likert scale: 1= strongly disagree, 5 = strongly agree SD: standard deviation				

Our study has some limitations. First, it was an evaluation of small numbers of 3D models and surgeons. Second, no accepted, validated universal questionnaire for the rating of surgeon satisfaction is available; thus, we needed to create one. Furthermore, if the osteotomies were simulated on the 3D models before the surgical interventions, this study would have been more valuable.

CONCLUSIONS

3D modeling of foot deformities is more informative than virtual 3D videos. However, with consideration of costs and long processing times, 3D printing may be used optimally for rare deformities. When considering the role of touch sense in surgical learning, 3D modeling gives more detailed and more satisfactory planning than virtual 3D videos. 3D modeling is more useful for young surgeons, and it will be used mainly for education in the future.

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