OPEN Research Article

Improving Patient Understanding of Femoroacetabular Impingement Syndrome With Three-Dimensional Models

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ABSTRACT

Introduction: Three-dimensional (3D) printed models may help patients understand complex anatomic pathologies such as femoroacetabular impingement syndrome (FAIS). We aimed to assess patient understanding and satisfaction when using 3D printed models compared with standard imaging modalities for discussion of FAIS diagnosis and surgical plan.

Methods: A consecutive series of 76 new patients with FAIS (37 patients in the 3D model cohort and 39 in the control cohort) from a single surgeon's clinic were educated using imaging and representative 3D printed models of FAI or imaging without models (control). Patients received a voluntary post-visit questionnaire that evaluated their understanding of the diagnosis, surgical plan, and visit satisfaction.

Results: Patients in the 3D model cohort reported a significantly higher mean understanding of FAIS (90.0 ± 11.5 versus 79.8 ± 14.9 out of 100; P = 0.001) and surgery (89.5 ± 11.6 versus 81.0 ± 14.5; P = 0.01) compared with the control cohort. Both groups reported high levels of satisfaction with the visit.

Conclusion: In this study, the use of 3D printed models in clinic visits with patients with FAIS improved patients' perceived understanding of diagnosis and surgical treatment.

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Femoroacetabular impingement syndrome (FAIS) is defined by a triad of symptoms, examination signs, and imaging findings that represent a motion-related disorder of the hip from premature contact between the proximal femur and the acetabulum.[1] The abnormal hip morphology and motion in FAIS can lead to soft-tissue damage of the hip joint and osteoarthritis.[2] FAIS can be secondary to cam and pincer morphologies, which are femoral head-neck and acetabular-based disorders, respectively.[3,4] These complex three-dimensional (3D) morphologies can be challenging for patients to comprehend. The potential sequelae of FAIS can lead to osteoarthritis, further increasing the importance to explore patient education regarding their pathology.[3,4] Educating patients about their injury can help engage patients in a shared decision-making process, improve overall patient satisfaction, and lead to better health outcomes.[5-7]

Effective patient education remains an obstacle not only in orthopaedic surgery but in medicine in general. Educational materials are often written far above reading levels, making the physician the sole educator, which may further complicate physician-patient communication.[8-11] In orthopaedics, patients with osseous pathologies receive education using imaging modalities such as radiographs, CT scans, and magnetic resonance imaging (MRI). Interpretation of these studies is challenging and may be difficult for many patients with no prior medical experience to interpret these imaging modalities and fully understand their pathology and surgical plan.

3D printing is a common and inexpensive technique that has gained increasing popularity in the healthcare field, especially surrounding surgical planning.[12] Previous studies in nonorthopaedic disciplines have found that 3D printed models can improve patient understanding of their related anatomy, physiology, surgical plan, and the associated risks of their condition.[13,14] However, there remains a gap in the current literature exploring the specific effect 3D models can have on patient education in orthopaedic surgery, and more specifically for patients with FAIS.

This study aimed to investigate the effect of 3D printed models on patient education and clinic visit satisfaction for the diagnosis of FAIS. We hypothesized that the use of 3D models would help increase patient's knowledge of their disease process, improve their understanding of the surgical management, and improve satisfaction with their clinical visit in comparison with the standard methods used to educate patients.

Methods

We prospectively collected data from new patients older than 18 years who presented to a single orthopaedic surgery sports medicine clinic with the diagnosis of FAIS from February 2022 through February 2023. All patients met with the same sports medicine fellowship-trained attending surgeon to discuss their condition and surgical treatment. We excluded patients with hip diagnoses other than FAIS, patients who were non–English-speaking, or those who declined the survey.

Patients were consecutively enrolled into the 3D model cohort until reaching 37 responses and then consecutively enrolled into the control cohort to a minimum of 37 responses (patients were not randomized). Patients were blinded to the participation of a comparative group. For the 3D model cohort, the surgeon used a representative 3D printed model of FAI (Figure 1) in addition to patient-specific imaging (radiographs, MRI) to describe the diagnosis and surgical treatment. In the control group, the 3D models were not used—an identical explanation process was used reviewing patient-specific imaging (radiographs, MRI) along with a verbal discussion of the relevant surgical treatment and pathology. Each clinic visit was approximately 30 minutes, and care was taken to contain each clinical visit within this allotted time, to limit potential bias in explanation between the two cohorts.

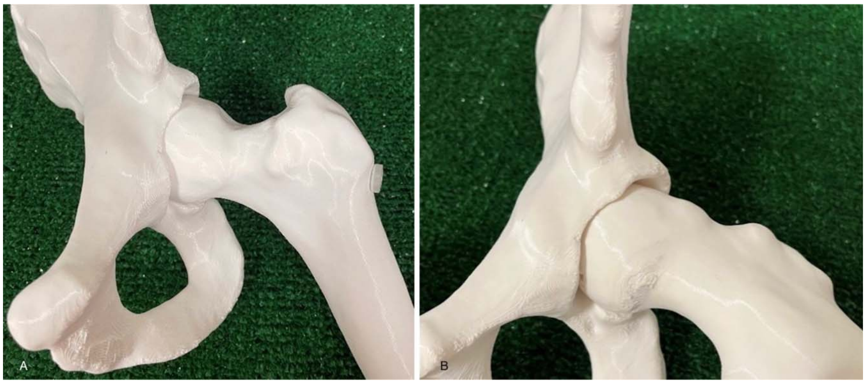
At the conclusion of the clinic visit, patients were informed about this study's voluntary survey and our goals of evaluating patient understanding of FAIS. Before leaving the office, patients were asked to complete a seven-question anonymous voluntary survey that was distributed and stored using a Quick Response code into a secure REDCap database. Patients were asked a series of questions on their understanding of their injury, surgery plan, their level of satisfaction with their clinic visit, and their highest level of education (Figure 2). Patient understanding of injury and surgery was evaluated on a continuous level scale from 0 (no understanding) to 100 (expert understanding). The questions used for visit satisfaction were based on the Consumer Assessment of Healthcare Providers and Systems Clinician & Group Adult Survey 3.0,[15] a validated survey for the use of improving patient experiences in the healthcare setting. Level of education was collected to minimize education as a confounding variable.

This study was approved by the University of Washington Institutional Review Board and remained in accordance throughout the duration of this study.

3D Model Printing

The 3D models used in this study were printed using preoperative CT scans of patients with known FAIS pathology from our hospital imaging system. The CT data were stored in a Digital Imaging and Communications in Medicine format and transferred to a Prusa i3 MK3S+ 3D printer, using polyethylene terephthalate glycol to print each model. Each model was assembled to reflect an anatomic hip and was printed in two parts: a hemi-pelvis and a corresponding proximal femur.

Figure 1



Photographs of the left hip "cam" 3D printed model used for clinic discussions in patients with FAIS (**A**). In the photograph on the right, the femur is externally rotated to demonstrate the cam morphology (**B**). 3D = three-dimensional.

These were then connected by drilling a 5-mm hole from the greater trochanter through the acetabulum, threading an elastic band, and securing with buttons. Both a primarily cam model and a primarily pincer model were created. An example of the printed cam model is shown in Figure 1.

Statistical Analyses

Statistical differences were calculated using Student *t*-test when comparing means and chi-square test when comparing proportions between groups. A P-value $<$ 0.05 was statistically significant. We also stratified patient understanding based on education level, comparing participants with greater than 16 years of education versus those with less than 16 years. A literature review of studies evaluating understanding of medical/surgical pathologies when using 3D models was performed but did not yield applicable averages necessary to perform a priori power analysis. A power analysis was conducted by first obtaining preliminary survey results of 20 patients to determine mean and standard deviation for all quantitative values. Power analysis was then performed with the means and standard deviations observed, using an alpha value of 0.5 and beta value of 0.2. An effect size of 0.68 was observed when comparing patients' understanding of their injury when the

Figure 2

Post Clinic Questionnaire

1.) Did your doctor show you a plastic 3D printed model?
- ○ Yes
- ○ No

2.) Do you understand your injury after this visit?
0 (No understanding) to 100 (Expert Understanding)

3.) Did your doctor talk about surgery options today?
- ○ Yes
- ○ No

4.) Do you understand the surgery for your injury?
0 (No understanding) to 100 (Expert Understanding)

5.) Did the doctor explain things in a way that was easy to understand?
- ○ Yes, definitely
- ○ Yes, somewhat
- ○ No

6.) Would you recommend this provider's office to your family and friends?
- ○ Yes, definitely
- ○ Yes, somewhat
- ○ No

7.) How many years of school have you completed?
- ○ Less than 9
- ○ 9 – 12
- ○ 13 – 16
- ○ Greater than 16

Example of the questionnaire that was administered to patients immediately after their clinic visit to investigate patient education (questions 2 and 4) and satisfaction (question 5 and 6).

3D model was used. A sample size of 35 was found to be powered to detect a 10% difference in understanding of patients' injury. To account for the possibility of incomplete questionnaires, a total of 76 patients with FAIS were consecutively enrolled, 37 patients in the 3D model cohort followed by 39 patients in the control cohort.

Results

A significantly greater understanding of FAIS diagnosis and surgery was noted in the 3D model group versus the control group (Table 1). For Survey Question 2, "Do you understand your injury after this visit?", respondents in the 3D model and control cohorts averaged a response of 90.0 ± 11.5 and 79.8 ± 14.9 of 100, respectively (P = 0.001). For Survey Question 4, "Do you understand the surgery for your injury?", an average response of 89.5 ± 11.6 of 100 was found in the 3D model cohort, versus 81.0 ± 14.5 in the control group (P = 0.01). As shown in Table 1, both groups demonstrated satisfaction with the visit and there was no statistically significant difference between the two groups for either Question 5 or 6 (P = 0.54 and 0.99, respectively).

Nearly all patients had completed high school education (86%) and half (50%) had completed education beyond an undergraduate degree. In the 3D model group, two patients had less than 9 years of education, seven had 9 to 12 years, 10 had 13 to 16 years, and 18 had greater than 16 years. In the control group, 0 patients had less than 9 years, two had 9 to 12 years, 17 had 13 to 16 years, and 20 had greater than 16 years. Among the two cohorts, there was no significant difference in education level (P = 0.08).

When education level was stratified among those with greater than 16 versus 16 or fewer years of education, it was found that those with 16 or fewer years of education demonstrated a higher level of understanding of their injury when shown a 3D model (91.3 versus 79.8; P = 0.01) compared with those in the control group. In patients with greater than 16 years of education, there was only a trend toward a significant increase in understanding compared with the control group (P = 0.06). Education level did not significantly increase or decrease patients understanding for their surgical plan', but there may be a trend in favor of the 3D model cohort (Table 2).

Discussion

This is the first study to our knowledge that comparatively assesses the effect of using 3D printed models on clinic visit education and satisfaction in patients with FAIS. We found that patients who were shown 3D models reported a higher level of understanding of their diagnosis (90/100 versus 80/100, P = 0.001) and surgical plan (90/100 versus 81/100; P = 0.01) when compared with patients not shown a model. Both patient cohorts were shown their own individual imaging and spent their clinic visit with the same surgeon. In both groups, patients reported high levels of satisfaction with their care. While our secondary analysis found that patients with 16 or fewer years of education benefitted the most from the 3D models regarding understanding their injury, we may have been underpowered to detect a

Table 1. Patient Survey Responses

Survey Question	3D Model (n = 37)	Control (n = 39)	P
"2.) Do you understand your injury after this visit?"	90.0 ± 11.5[a] (n = 37)	79.8 ± 14.9[a] (n = 39)	0.001[b]
"4.) Do you understand the surgery for your injury?"	89.5 ± 11.6[a] (n = 33)	81.0 ± 14.5[a] (n = 31)	0.01[b]
"5.) Did the doctor explain things in a way that was easy to understand?"	Yes, definitely: 35 (95%) Yes, somewhat: 2 (5%) No: 0	Yes, definitely: 34 (87%) Yes, somewhat: 5 (13%) No: 0	0.54
"6.) Would you recommend this provider's office to your family and friends?"	Yes, definitely: 34 (92%) Yes, somewhat: 3 (8%) No: 0	Yes, definitely: 35 (92%) Yes, somewhat: 3 (8%) No: 0	0.99

3D = three-dimensional.
[a]Responses were on a continuous scale of 0 (no understanding) to 100 (expert understanding).
[b]Denotes statistical significance ($P < 0.05$).
Comparison of patient responses to the post-clinic visit survey by cohort—patients who saw the 3D printed femoroacetabular impingement hip model ("3D model") versus patients who did not see the model ("control").

Table 2. Patient Understanding and Education

Education Level and Survey Question	3D Model (n = 37)	Control (n = 39)	*P*
"2.) Do you understand your injury after this visit?"			
Greater than 16 yr	88.7 ± 12.9 (n = 18)	79.8 ± 15.1 (n = 20)	0.06
Less than 16 yr	91.3 ± 10.1 (n = 19)	79.8 ± 15.1 (n = 19)	0.01[a]
"4.) Do you understand the surgery for your injury?"			
Greater than 16 yr	87.6 ± 12.1 (n = 17)	78.9 ± 14.1 (n = 17)	0.07
Less than 16 yr	91.50 ± 11.0 (n = 16)	83.2 ± 15.0 (n = 15)	0.09

3D = three-dimensional.
[a]Denotes statistical significance ($P < 0.05$).
Education level was stratified in each cohort to investigate whether there was an intercohort difference between levels of education and reported patient understanding of their injury and surgical plan. All responses were on a continuous scale of 0 (no understanding) to 100 (expert understanding).

difference in the more educated cohort or the survey question on understanding of surgery, as sample size in each subgroup was less than 35.

Our study has several limitations. One limitation was the small sample size that made it difficult to complete a robust subgroup analysis on the effect of patient education level on patient understanding; however, both groups had a similar mean education level to minimize confounding. Furthermore, the sample size necessary to adequately power this study to detect a 10% difference in understanding of a patient's surgical plan was greater than the sample size ultimately used, indicating the significantly improved understanding of the surgical plan discussed may represent a type 1 error. Another limitation was the possibility of bias in the physician's description of the diagnosis and surgery. We tried to minimize this by only including one surgeon, but there could have been subtle bias in the explanation as the surgeon was not blinded to whether a 3D model was used. In addition, our method for testing patient understanding was based on patients' perceived understanding of their pathology and its treatment. We included two nonvalidated questions (Questions 2 and 4) for patient understanding, and we hoped by creating a continuous scale for these questions they would be more precise and accurate than a categorical/ordinal scale. A more objective measure of testing patient education could have been beneficial, such as a "quiz" on FAIS pathogenesis and treatment. However, to our knowledge, there are no validated quiz questionnaires. In addition, it would have been difficult to construct a list of questions that could have been appropriate for all educational levels and truly demonstrate a patient's understanding of their pathology and treatment plan. Furthermore, reaching an adequate number of surveys may have an additional barrier because a longer or more confusing survey would have likely resulted in fewer responses. Finally, we arbitrarily established a difference of 10% in our questionnaire as clinically significant. Although the difference we found in understanding of injury and surgery was statistically significant, it is difficult to know whether the difference was truly clinically significant.

The use of 3D models has gained interest in the field of orthopaedics over the past decade, particularly for surgical planning and implant design.[16-22] A few studies have also assessed the effect 3D models have on patient and resident education and satisfaction. Bockhorn et al[23] performed a case series on the application of 3D printing for preoperative planning in hip preservation surgery. They administered a Likert-style survey to 10 hip preservation surgeons, 11 orthopaedic surgery residents, and 10 patients who all used 3D printed models in the preoperative period. Similar to our study, they reported that all but one patient agreed that 3D models helped them understand their pathology and made them more comfortable with their surgical plan. All residents strongly agreed or agreed that 3D printed models helped them feel more comfortable with the surgical procedure and preferred 3D printed models over standard imaging modalities when understanding hip pathology. In contrast to our study, this study lacked a comparison group and had a smaller sample size. Other studies have demonstrated the benefits of 3D printed models among residents, such as improving interobserver reliability of a proximal humerus fracture classification system, compared with radiographs and CT alone.[24]

A study by Sugand et al investigated the role of anatomical shoulder and knee models on patient satisfaction during the informed consent process for surgery. They conducted a trial in which the intervention group (n = 26) was shown a 3D shoulder or knee model along with a verbal explanation and a control group (n = 26) was given only a verbal explanation. When comparing the intervention group with the control group, they found that patients were 7.4% (P = 0.01) more satisfied during the consent process when shown a model.[25] This differed from our analysis because we found no difference in patient satisfaction between patients who did or did not see a 3D model. This difference may be because we used the validated Consumer Assessment of Healthcare Providers and Systems questions which did not allow for as granular of a response difference, whereas Sugand et al used the Medical Interview Satisfaction Scale. Also unlike our study, the investigators did not assess patient education level or understanding of injury/surgery, and they did not use pathology-specific models to educate patients (they used generic models of the shoulder and knee).

Outside of orthopaedics, pediatric general surgery literature on hepatic tumors and urology literature on kidney tumors have shown that 3D models improve both trainee and patient understanding of patient anatomy, pathology, and surgical treatment.[13,14,26]

Our results suggest that the use of 3D models markedly increases patients' perceived understanding of their pathology and treatment in FAIS, regardless of education level. These models thus could play a notable role in educating patients with FAIS, and perhaps other structural orthopaedic pathologies. Previous studies have demonstrated that many of the educational materials accessible to patients may be far above the national recommendations. Specifically, Kiapour et al[9] investigated the readability of online materials for FAIS and found that, on average, materials were 2-grade levels higher than recommended. In gynecology, Hallock et al found that women who were highly satisfied during their consent process were more likely to have scored higher on an informed consent questionnaire that demonstrated their understanding. These findings indicate a possible barrier to healthcare accessibility and patient education. In our results, we found that patients with 16 or fewer years of education benefitted more than those with greater than 16 years of education when seeing the 3D models. This suggests that 3D models are accessible to all education levels unlike some educational materials that may be above the reading level of patients.[9] It is imperative that patients are informed during the surgical consent process as it affects their ability to make informed decisions and level of expectations which has been shown to influence healthcare outcomes.[7,27,28] Since the completion of this study, we have changed our practice to use 3D printed models whenever possible in clinic visits for FAIS, and we encourage future research on the educational impact of 3D models in other aspects of orthopaedics, including larger subgroup sample sizes and a greater diversity of pathology.

Conclusion

Patients educated with 3D printed models reported a markedly higher level of understanding of their FAIS diagnosis and surgical plan compared with patients who were not shown a 3D model. Use of 3D models had a notable benefit for patients with 16 or fewer years of education, and thus these models may improve orthopaedic healthcare delivery across all populations.

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