Physical Education, Health and Social Sciences

https://journal-of-social-education.org

E-ISSN: 2958-5996
P-ISSN: 2958-5988

Enhancing Preoperative Patient Understanding and Nurse-Led Communication Using 3D-Printed Surgical Models: A Multimodal Study in the Surgical Departments of Saidu Teaching Hospital, Swat.

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DOI: https://doi.org/10.63163/jpehss.v3i2.294

Abstract

Background: Patient education before surgery proves vital because it helps patients grasp their condition better and lowers their anxiety and delivers better satisfaction results. Patients find insufficient understanding when they rely on traditional methods which include verbal explanations together with simple 2D images. Staff nurses work with 3D-printed surgical models to teach preoperative patients better in low-resource healthcare facilities.

Aim: This research evaluates how 3d-printed anatomical models assist nurses in delivering preoperative education to evaluate patient comprehension, minimize anxiety, and boost patient satisfaction in surgical departments.

Methods: Sixty elective surgical patients underwent research at Saidu Teaching Hospital, Swat, Pakistan, with thirty patients in the intervention group and thirty patients in the control group. Preoperative patient counseling included patient-specific 3D-printed model demonstrations for the intervention group but the control patients received standard education methods. The research relied on comprehension questionnaires together with APAIS (anxiety scale) measurements and a satisfaction rating assessment tool for data collection. Semi-structured interviews were conducted with both 10 patients and 10 nurses, producing qualitative data.

Results: The participants who received patient-specific 3D-printed models experienced better understanding results (mean +8.3, $p < 0.001$) as well as reduced anxiety scores (mean -7.7, $p < 0.001$) compared to standard education model patients. Patients in the intervention group demonstrated superior levels of satisfaction, since 73% of them expressed very high satisfaction. The analysis yielded four main themes, which included patients getting better comprehension alongside better emotional reassurance and improved communication methods. The nurses articulated their training needs as another significant theme.

Conclusion: Through the use of 3d-printed surgical models, nurses achieve better patient understanding while simultaneously reducing patient anxiety and improving their educational satisfaction. Resource-limited healthcare facilities can implement 3D-printed surgical models that create positive impacts through their deploy ability.

Keywords: 3D-printed models, preoperative education, nurse-led communication, surgical nursing, patient understanding

Introduction

The surgical care environment requires complete patient education and purposeful clinical communication because they lead to superior results. Patients often struggle to understand clinical terms during verbal explanations and see 2D images because these traditional preoperative education methods lack a full understanding of the relationship between medical language and patient knowledge (Cheng et al., 2025). The research assesses how 3D-printed surgical models, which show individual patient anatomical features, help preoperative teaching improve patient comprehension and nurse-led communication methods (Sun et al., 2020). This investigation uses a multimodal intervention based on tactile stimulation, visual presentation, and verbal education to improve the patient-clinician relationship, decrease preoperative stress, and enhance the informed consent process (Wang et al., 20242024).

Preoperative education provides structured information before surgical procedures, patient understanding describes surgical procedure knowledge and risk comprehension, nurse-led communication involves patient information exchange under nursing guidance, while 3D-printed surgical models are additive-manufactured physical replicas that demonstrate precise patient anatomy (Lv et al., 2024). The fundamental component of patient-centred care, which represents preoperative education, faces limitations because of built-in obstacles (Harms & Elisabet, 2020). When patients receive complex surgical information through descriptions and static two-dimensional images, it becomes challenging for them to understand surgical procedures because such approaches create confusion and anxiety increases (Kang, 2022).

Research demonstrates that 60% to 80% of surgical patients fail to keep details from their preoperative meeting because they remember only 50% of the information said. This deficiency impairs their decision-making capacity (Doré, 2022). Nurses who function as primary healthcare educators must clarify surgical information to patients, yet face obstacles using traditional education materials (Cheng et al., 2021). The existing challenges in patient education emphasize the requirement for advanced educational resources that match different learning approaches among patients and adjust for their health understanding levels (Schultz et al., 2023).

Medical technology based on 3D printing has revolutionized healthcare by developing personalized organism models that help surgeons plan operations, educate medical practitioners, and train upcoming professionals (Harris et al., 2024). The models enable patients to touch and see replicas of their body parts, which recreate human anatomy. Using 3D-printed models in cardiology and orthopedics leads to better surgical results through advanced preoperative strategy development and precise intraoperative procedures (Gharleghi et al., 2021). Patient education applications of three-dimensional printing remain unexplored, preventing better nurse-patient communication from developing. 3d models convert medical images into replicable objects, which help patients view treatment options and anticipated results in ways that overcome cognitive obstacles better than regular methods (Sun & Wee, 2022).

The preoperative care process greatly depends on nurse-mediated patient-surgeon communication because nurses are essential middlemen between these two parties. The nursing community plays a crucial role in preoperative care, yet they encounter numerous obstacles due to limited time availability, mixed information delivery, and their dependence on non-uniform educational resources (McMenamin, 2023). 3D-printed models that nurses use in patient interactions help maintain consistent information delivery while reducing patient confusion and enhancing their sense of trust in providers (Ron et al., 2025). A nurse describing hernia repair to patients using three-dimensional visualization demonstrates a surgical procedure by identifying bodily elements that align to explain the scope and risk information (Inagaki et al., 2023).

Patients who can touch the models acquire the ability to formulate specific questions during collaborative interactions with healthcare providers. Many healthcare facilities embrace multimodal approaches that link visual and auditory, and tactile components for better patient

knowledge retention and satisfaction results (Kennedy & Parish, 2021). According to cognitive load theory, information divided between different sensory channels helps mental workload decrease while comprehension strengthens. Doctors should utilize preoperative situations to merge 3d models with both verbal explanations and illustrated pamphlets or digital animations to help different learner types (McPherson, 2023). Initial research in oncology and pediatric settings showed that using several learning methods helps patients remember information better while minimizing stress levels, although applications involving nurses as primary educators in general surgical settings have not been fully explored (Birchwood, 2021).

Research-based evidence about using 3D-printed models in standard preoperative clinical practices remains limited in quantity. Most studies analyze applications administered by surgeons without examining the educational responsibility of nurses. Existing research lacks investigations of 3D models together with virtual reality and structured counseling to develop synergic effects for patient care (Tang et al., 2023). A study investigates patient outcomes through the implementation of nurse-facilitated 3D models as part of multimodal interventions across different surgical specialties while evaluating understanding and related psychological measures (Kumlin et al., 2022).

This research coincides with worldwide initiatives focusing on individualized healthcare because it examines the combination of innovative technologies with nursing practice (Kumlin et al., 2022). The successful implementation of 3D-printed models would transform standard preoperative education approaches by allowing nurses to provide stable, engaging and reachable information. The study aims to deliver practical methods that enhance communication techniques and diminish health inequalities while maximizing surgical results through innovation in patient-clinician interaction.

Methodology

The surgical departments of Saidu Teaching Hospital, Swat, Pakistan, served as the study location for this 3d-printed surgical model evaluation project, which assessed their effectiveness for improving preoperative patient understanding through nurse-led communication. Sixty adult patients underwent testing before and after the study through a quasi-experimental trial using 30 patients in the intervention group and 30 patients in the control group who received surgeries from the general surgery, Surgical specialty groups composed the sample through purposive sampling, followed by participant distribution based on their specialty, which also ensured Pashto language fluency and ability to provide consent and elective surgery status.

Standard care was provided to both intervention and control group participants. Still, the intervention recipients accessed preoperative education through customized 3d-printed models alongside verbal descriptions and 2D images, while control participants only received verbal and 2D education. Administration of the study required CT/MRI patient data inputs for developing 3d models through 3d Slicer software that was further printed by FDM technology using PLA filament. The models concentrated on vital anatomical structural components including tumor positions and fracture areas with surgical expertise validating the authenticity of the representation. The nurses participating in the intervention received formal standardized training to achieve uniformity when delivering the counseling with the models. The hospital's Institutional Review Board (IRB) approved the ethical aspects of the study, while participants provided their informed consent to join the research. Both quantitative evaluations and qualitative interview methods were incorporated to understand this intervention's complete effects on patient understanding and communication quality between nurses and patients.

Intervention Protocol

Intervention Group: Patients attended a 15–20-minute nurse-led session using the 3D model to explain the procedure, risks, and postoperative care. Sessions included tactile exploration of the model, visual aids (color-coded pathology), and verbal reinforcement.

Control Group: Patients received routine preoperative counselling (verbal explanations, 2D scans, and pamphlets).
Both groups received identical procedural information to isolate the effect of the 3D model.

Data Collection
Quantitative Measures:
Patient Understanding: Measured via a 10-item questionnaire (score 0–20) pre- and post-intervention, testing knowledge of anatomy, procedure steps, and risks.
Anxiety Levels: Assess using the Amsterdam Preoperative Anxiety and Information Scale (APAIS) pre- and post-intervention.
Satisfaction: Rated on a 5-point Likert scale post-counselling.
Qualitative Measures:
Semi-structured interviews with 10 intervention-group patients and 10 nurses explored perceived benefits, challenges, and suggestions for improvement.

Data Analysis
The analysis of quantitative data occurred using SPSS version 26. The paired t-test for pre-post score assessment occurred within individual groups, while independent t-tests compared the outcomes across different groups. Multiple regression analysis determined the factors that influenced both understanding and anxiety reduction. Researchers conducted thematic analysis on qualitative data using NVivo software to develop a coding structure into themes.

Results and analysis
Demographic Characteristics of Participants.
The intervention and control participants demonstrated similar population ages because Intervention-group members averaged 45.2 ± 11.5 years old, and Control-group members averaged 43.8 ± 10.9 years old. Participants showed similar gender proportions because the intervention group contained 56.7% males, whereas the control group maintained 53.3% males. The intervention group contained 43.3% participants with intermediate or higher education compared to 33.3% in the control group, yet both groups showed most participants ending their studies at matric or below. (Table 1)

Table 1: Demographic Characteristics of Study Participants

Variable	Intervention Group (n = 30)	Control Group (n = 30)	Total (n = 60)
Mean Age (years)	45.2 ± 11.5	43.8 ± 10.9	44.5 ± 11.2
Gender			
Male	17 (56.7%)	16 (53.3%)	33 (55%)
Female	13 (43.3%)	14 (46.7%)	27 (45%)
Education Level			
No formal education	5 (16.7%)	6 (20.0%)	11 (18.3%)
Primary to Matric	12 (40.0%)	14 (46.7%)	26 (43.3%)
Intermediate & Above	13 (43.3%)	10 (33.3%)	23 (38.3%)

Patient Understanding Scores
Intervention group subjects improved understanding during the study period by progressing from an initial score of 8.2 ± 2.1 to 16.5 ± 1.8 (+8.3, $p < 0.001$). The participants in the control group had a smaller statistically meaningful improvement from 8.4 ± 2.3 to 11.2 ± 2.5 (mean difference = +2.8, $p = 0.002$). Patient understanding benefited greatly from surgical 3D-printed models beyond traditional educational methods. (Table 2).

Table 2: Patient Understanding Scores (Pre and Post-Intervention)

Group	Pre-Test Mean ± SD	Post-Test Mean ± SD	Mean Difference	p-value
Intervention (n=30)	8.2 ± 2.1	16.5 ± 1.8	+8.3	<0.001
Control (n=30)	8.4 ± 2.3	11.2 ± 2.5	+2.8	0.002

Anxiety Scores

The subjects in the intervention group demonstrated lower preoperative anxiety as measured by APAIS scores, which decreased from 19.1 ± 3.2 to 11.4 ± 2.8 (mean reduction = -7.7) at $p < 0.001$. The control participants exhibited less anxiety reduction, although their scores showed statistically important changes from 18.7 ± 3.0 to 15.9 ± 2.9 (difference of -2.8, $p = 0.007$). The use of 3D-printed surgical models proved better than traditional educational tools at decreasing preoperative anxiety in patients. (Table 3).

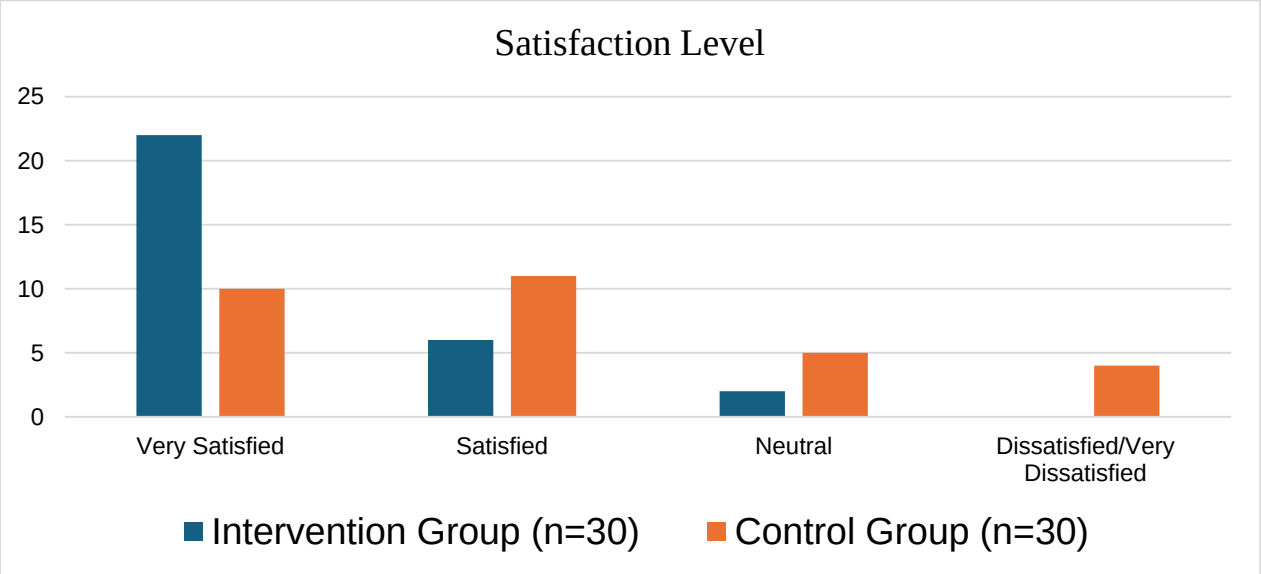
Table 2: Anxiety Scores (APAIS) Pre and Post-Intervention

Group	Pre-APAIS Mean ± SD	Post-APAIS Mean ± SD	Mean Reduction	p-value
Intervention (n=30)	19.1 ± 3.2	11.4 ± 2.8	-7.7	<0.001
Control (n=30)	18.7 ± 3.0	15.9 ± 2.9	-2.8	0.007

Patient Satisfaction Post-Counselling

Participating patients in the intervention group demonstrated higher satisfaction levels, where 73% expressed very satisfied, contrasted to 33% in the control group. The intervention group showed higher satisfaction levels because they did not report any dissatisfied responses, whereas the control group included 13% dissatisfied patients along with 17% neutral patients. Data shows that patients experienced higher levels of satisfaction regarding preoperative education by implementing 3D-printed models. (Figure 1)

Figure 1: Patient Satisfaction Post-Counselling



Multivariate Regression

Being part of the intervention significantly enhanced patient understanding levels with a statistical association of $\beta = 7.82$ ($p < 0.001$). Older patients demonstrated slightly fewer comprehension levels while receiving healthcare, yet this difference was non-statistically significant ($\beta = -0.11$, $p = 0.12$). According to the analysis results, better-educated patients showed enhanced benefits from the intervention ($\beta = 0.24$, $p = 0.04$). (Table 3).

Table 3: Multivariate Regression Predictors of Patient Understanding

Variable	β Coefficient	p-value
Group (Intervention)	7.82	<0.001
Age	-0.11	0.12
Education Level	0.24	0.04

Thematic Analysis of Patient and Nurse Perspectives on 3D-Printed Surgical Models in Preoperative Education

Patients and nurses generated four essential themes in their qualitative findings by incorporating 3D-printed surgical models into preoperative educational practices. Patients consistently showed better understanding after seeing the models because they could "see what was inside them" regarding their medical situation. Patients' improved comprehension came to light through nurses' lowered number of questions to redundant levels. Patients displayed emotional reassurance through their increased confidence after speaking with the model, and nurses observed lower patient anxiety levels. People used the model to help simplify medical terminology while they built better communication connections between nurses and their patients. Additional work needs to be done in the model development because patients encountered problems with its dimensions, alongside nurses requiring better training methods to depict anatomical details accurately. This demonstrates the continual necessity to advance technical capabilities and user training standards. (Table 4).

Table 4: Thematic Summary from Qualitative Interviews

Theme	Patient Perspective (n=10)	Nurse Perspective (n=10)
Enhanced Understanding	"I could finally see what was inside me."	"Patients asked fewer repeated questions."
Emotional Reassurance	"Touching the model made me feel more confident."	"They were visibly calmer after seeing the model."
Communication Aid	"The nurse explained better with the model than before."	"It helped me explain complex terms simply."
Challenges & Suggestions	"Some models were small in size."	"Need more training to handle detailed anatomical structures."

Discussion

The research investigated how 3d-printed surgical models functioned as an improvement tool for surgical unit preoperative patient education and nursing communication methods. 3d models provided important improvements in surgical procedure understanding and decreased patient anxiety and enhanced patient satisfaction about their experience with preoperative counselling. The research findings demonstrate the importance of using picture-based tactile learning aids as solutions to communication barriers, which commonly affect patient educational programs throughout traditional healthcare practices, particularly in resource-limited regions like rural Pakistan.

Previous international research confirms that 3D-printed anatomical models provide valuable educational advantages for patients. Chinese participants who watched three-dimensional images during preoperative consultations achieved higher understanding than patients who received traditional counselling care, according to Kumlin et al. (2022). Gerup et al. (2020) confirmed that 3d printing aids patients by providing enhanced confidence alongside clearer comprehension for surgical consent decisions. Research evidence consistently validates the use of customized patient anatomical models, which help patients acquire more health knowledge and make better decisions about their healthcare. The current study provides original findings through its assessment of nurse-led education sessions in a low-resource environment, which validates that nurses can deliver detailed information using these educational tools.

Patient education during preoperative periods mostly involves surgeons, according to high-income research. Yet, this study features nurses as principal educators following surgeon involvement in high-income studies where nurse-led education methods succeed. The low physician-patient numbers in Pakistan and the nursing staff delivering most patient communication require this emphasis. Barchielli et al. (2021) established through their work that nurse-led interventions drive better patient understanding, together with reduced anxiety, specifically in preoperative settings. The described framework receives experimental validation through research demonstrating how nurses can create informative education while providing emotional comfort through proper training and suitable tools.

Many intervention group patients reported success with understanding, yet contradictions arose in which patients expressed reservations about the 3d models' scale and level of detail. The trial participants described their experiences with 3d models in Wang et al., (2020) because the detailed anatomical features sometimes overwhelmed patients when experts did not provide guidance to interpret them. The nursing training, accompanied by simplified model labelling, helped address this problem, but demonstrates the requirement for continuous development of understanding-friendly model designs specifically for less educated populations.

The results showed that patients in the intervention group experienced much more anxiety relief than patients in the control group, thus confirming that physical visual tools help patients gain comfort through a clearer understanding of surgical procedures. The findings of Pooresmaeil et al. (2022) demonstrated that visual educational aids led to considerable preoperative anxiety reduction among major surgical patients. The intervention implemented physical touchable models instead of digital simulations utilized in the previous study. The physical contact with the surgical models seemed to enhance participant comfort according to their words, including "touching the model made me feel confident.

The primary value of this research applies to low- and middle-income countries because health literacy continues to be an obstacle to effective patient care. Our healthcare setting lacked technologically advanced infrastructure and simulation labs so the affordable 3D-printed physical models became a viable educational solution. The study matches the results of Perin et al,. (2021) that demonstrate how 3D printing technologies can function in restricted environments after modification for specific local requirements. The findings from this study confirm these recommendations for further exploration of production methods that scale and originate from within rationing countries during medical education (Abbasnia et al., 2023).

Nurses in Pakistani teaching hospitals delivered preoperative education utilizing 3D-printed surgical models, improving patient comprehension, decreasing their anxiety, and enhancing their satisfaction rates (Besklubova et al., 2021). The study produced outcomes which support wider international research, yet maintains a distinct Pakistani medical perspective (Niburski et al., 2020). The study demonstrates how nurse-led technology-supported educational methods show great potential for change while facing the constraints of restricted learning population scope and participant numbers. Future research efforts should work on improving model development, growing sample numbers, tracking patient empowerment outcomes, and clinical compliance by utilizing these innovative approaches.

Conclusion

Including 3d-printed surgical models in nurse-led preoperative education leads to better patient understanding, lower anxiety, and elevated satisfaction rates in surgical environments. Memorable patient comprehension increased when nurse counsellors used visual and touch-based instruments to explain complicated body structure details and procedural elements, especially within Saidu Teaching Hospital's limited resource environment. Patients who receive specific healthcare education become more capable of making better care decisions, while nurses deliver holistic patient-oriented care that improves both patient knowledge and satisfaction. These findings will strengthen the development of surgical nursing as a field while

demonstrating the traditional clinical advantages of embracing innovative cost-optimized technologies in everyday healthcare practice.

Recommendations

I. **I. Institutional Adoption: Human healthcare facilities operating in low- and middle-income settings should implement standardized 3d-printed** model use in preoperative educational programs for better surgical patient communication and preparedness.
Medical institutions need to create educational programs that teach nurses to properly implement 3D models for therapeutic purposes in clinical settings by combining basic science knowledge with communication method instruction.

II. **Policy Integration:** The regulatory authorities and health decision-makers need to integrate 3D educational tools into their nationwide patient education standards, which focus primarily on surgical and preoperative care services.

III. **Further Research:** Multiple large-scale institutions should conduct research that confirms the results, studies how surgical outcomes evolve, and evaluates the economic value for diverse medical specialties.

IV. **Patient-Centered Design: Patient feedback should be the basis of future 3d** model development work to achieve clarity and cultural and reading level compatibility.

V. **Technological Support:** To achieve long-term sustainability of these solutions, health facilities should receive investments in fundamental 3d printing systems and software training programs in urban and rural medical facilities.

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