Individualized Design Application of 3-Dimensional Printing Navigational Template for Pedicle Screw Installation: A Training Case Report

Matthew Jianqiao Peng*, Ze Lin*, Erxing He*

* Matthew Jianqiao Peng, Ze Lin and Erxing He contributed equally to this work

Corresponding Author: Matthew Jianqiao Peng, e-mail: 18922346634@163.com

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Background: The proper installation for pedicle screws by the traditional method of surgeons dependent on experience is not guaranteed, and educational solutions have progressed from chalkboards to electronic teaching platforms. We designed a case of 3-dimensional printing drill guide template as a surgical application, which can accurately navigate implantation of pedicle screws, and assessed its effect for simulative training.

Material/Methods: We randomly selected a set of computed tomography data for spondylolisthesis. A navigational template of pedicles and screws was designed by software Mimics and Pro-E, where trajectories of directions and angles guiding the nail way were manipulated for screwing based on anatomy, and its solid model was fabricated by a BT600 3D printer. The screws were integrated and installed to observe their stability.

Results: The navigational model and custom spine implants were examined to be compatibly immobilized, because they are tolerant to radiation and stable against hydrolysis. The screw size and template were fit accurately to the vertebrae intraosseously, because the pilot holes were drilled and the trajectories were guided by cannulas with visible routes. During the surgical workflow, the patient reported appreciation and showed substantial compliance, while having few complications with this approach. Compared with fluoroscopy-assisted or free-hand techniques, the effect of simulative training during processing was excellent.

Conclusions: The surgical biomodel is practical for the procedural accuracy of surgical guides or as an educational drill. This fostering a style of “practice substituting for teaching” sets a paragon of keeping up with time and is worthy of recommendation.

Keywords: Surgery, Computer-Assisted • Virtual Reality • Camptocormia • Organisation for Economic Co-Operation and Development • Rigid Spine Syndrome • Osteoarthritis, Spine

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Introduction

In traditional surgery, orthopedist procedures are difficult to display with surgical plans based on 2-dimensional (2D) radiographs, and the risks of harmful radiologic exposure from operative fluoroscopies remain a concern. The conventional installation for pedicle screws that is dependent on surface landmarks orientated by experienced surgeons is not desirable, due to the limited information available. Thus, these surgical procedures have a longer duration and higher cost and are especially difficult for interns with less experience. Inaccurate screw placement can damage the spinal cord, resulting in upper, lower, or even general paralysis. The limitations and drawbacks of complications brought from percutaneous pedicle screw instrumentation include loose or broken postsurgical rods, bleeding, infection, and nerve or vessel misinjury. In 1998, Radermacher reported a case of screw installation using the computer-aided design (CAD) model [1], which was proven to be more accurate than traditional manipulation by investigations, due to the role of parameterization [2-5]. The specific advantages achieved with 3-dimensional printing (3DP) technology over traditional methods include the creation of patient-specific guides and templates, which are more precise and accurate, for reducing surgical time and cost. Compared with the method of computational instruments, individualized guides are advantageous in terms of efficiency and lower expense [6-8]. Currently, 3DP is being used in spinal surgery to build templates, implants, biomodels, and guides to optimize preoperative plans. 3DP can offer an alternative to traditional methods as a simple, convenient, low-cost, and complex toolkit to enhance the precise placement of pedicle screws.

Spinal surgery is inherently dangerous due to the delicate nature of the surrounding anatomy. An intraoperative guide, which is created following patient-specific instrumentation tailored to individual patients for complex anatomical reconstruction, can mitigate all risks associated with a surgical procedure and be applied with positive outcomes. Patient-specific instrumentation has a posterior structure congruent with the vertebral spine. Based on computer-assisted preoperative planning done for sizing, alignment, and bone cutting, it enhances stability and is unaffected by degenerative processes, which differs from traditional approaches. Accurate implantation is a key factor in the success of these operations. In the past, the installation angle was determined primarily by equipment positioning according to the surgeon’s experience, but was often inaccurate beyond the “safety spot”. 3DP facilitates the creation of patient-specific guides and templates, which assist the preoperative plan and thereby intraoperatively enhance the precision and accuracy of hardware placement. Patient-specific guides and templates are helpful for the 3DP technique in minimally invasive percutaneous surgery. The appreciation of abnormality through 3DP modeling provides tactile and visual sensation of the impaired structure, which improves the anatomic understanding of interns and allows for preoperative planning, reducing intraoperative neurovascular injury and allowing accurate placement based on those preplanned datasets [8]. 3DP implants have been successfully applied to spines, due to the small and complex osteologic anatomies, as well as the proximity of neurovascular structures at surgical sites. There are many specific applications in spinal surgery. For instance, in the field of surgical planning, Sugimoto et al reported that the usefulness of 3DP increases with the complexity of the pathology, with the surgeon’s ability to maneuver a model without having to mentally reconstruct multiple 2D images. Therefore, the improved visualization and preparation afforded by the use of individualized models have clinical benefits. In the field of surgical guides, Otsuki et al demonstrated that 3DP guides provide an extra benefit in revision surgery, in which screw insertion is more difficult due to morphology changes caused by the first operation. In the field of customized implants, Xu et al created a prosthesis with zero profile anteriorly for this purpose, minimizing the risk of dysphagia in their patients.

We hypothesize that 3DP templates of an external fixation base will produce outcomes similar to that of fluoronavigation. The pedicle screw is a technique of fixation popularly applied as an effective method of 3D stabilization of the vertebrae. Pedicle implantation is developed in dual directions: one approach is by using computational navigators, such as a C-arm X-ray or a computed tomography (CT) guide; another approach is by using a CAD navigational template. The minimally invasive percutaneous screw technique has become a quick, accurate, and safe method of spinal surgery, with fluoronavigative development [9]. However, its widespread application has been limited by the longer exposure and complex setup for navigation systems.

Currently, percutaneous fixation is an extensive method that provides adequate stability but demands detailed anatomic knowledge from surgeons to ensure that screws are installed in an ideal position. In addition to significantly improving surgical knowledge, the importance of education and training is to acquire the necessary skills to perform pedicle screw installation safely and effectively, which is critical to ensure the best outcomes for patients undergoing spinal surgery. Therefore, our clinical goal was to design a novel plate with custom CAD implants and trajectories by computer in advance, in accordance with specular models [10], and simply insert the screw by following a template that provides a solid foundation and a geometrical surface for mounting. Our research goal was to evaluate the effectiveness of 3DP templates, in comparison with fluoronavigation, to differentiate computational navigation from fluoronavigation. During these processes, surgical interns were trained to use medical imaging software, such as Mimics, to create patient-specific templates, in order to
reconstruct anatomical models, which is termed biomodeling [9,10]. Interns learned to pre-calculate direction and angulation for screw placement, to avoid the difficulties of searching for anatomic landmarks [11-14], and thus the old teaching pattern was upgraded to a level of “practical substitution for teaching” [15], resulting in our educational goal.

In this paper, we report a training case of pedicle screw installation by the 3DP application of a navigational template, which was superior to fluoronavigation.

Material and Methods

Materials

A CT scan of a spinal image was randomly chosen from a patient who met the criteria of vertebral instability requiring posterior lumbar interbody fusion at Guangzhou Medical University Affiliated Hospital in June 2021. All procedures were in accordance with the 1964 Helsinki declaration and with the ethical standards of the university committee (# 2022YL03005). The experimental equipment included a 64-row CT (Siemens, Germany) with the following setting parameters: voltage=120 kV, intelligent auto current=50-150 mA/s, pitch=1.0, slice thickness=0.6 mm, interval gap=5 mm, and field of view=350 mm × 350 mm; a BT600 3D printer with the following setting parameters: volume size=600×600×400 mm, material: photosensitive resin, slice thickness=0.03-0.25 mm, forming accuracy=±0.1 mm (L<100 mm)±0.1%×L (L≥100 mm), sweep speed max 20 m/s, standard 6-10 m/s, and facula diameter=0.05-0.5 mm, power=3KW; and reverse engineering software Mimics-19 (Materialise, Belgium) and ProEngineering-5.0 (Parametric Tech Corp, USA) [16].

Methodology

The primary aim of the 3DP-patient-specific model was to resemble the clinical case by providing an overview of the anatomic detail for the surgeons. Custom production was tailored as specific geometry of the clinical case. The operation was navigated by a model, to visualize the interventional outcome, including pedicle screw placement and spinal surgery applications, with the goal of designing a patient-specific guide. Statistical methodology for analysis was not essential, because it was a case report with a single sample, which is detailed in the previous section.

Design of Navigational Template

First, the creation of the patient-specific model extracts the targeted geometry from CT images with respect to the location of certain signal property. All *.dicom formats of medical images were inputted into a Mimics medical image processor, where a 3D spine was modeled after the following procedure [17]: bony segmentation → spinal mask → 3D calculation → smoothing. Under hyalinization, suitable directions and angles for screw installation were searched in the spinal model, where small cylinder shapes were created, representing the screw, and where the outer layers were surrounded, representing screw threads. Then, the trajectories were manipulated for navigation by using the process “Boolean subtract”. The previous mask was processed by the morphological operation dilate, the 3D model was calculated by Boolean subtract to get an outermost shell called “outerwear” matching the spine, and the position fit for the navigator was gained after moderate slicing. After manipulating the spinal model, the directions and angles that guided the navigator and the path of the nail were preplanned.

Design of Screw

We designed drill templates according to the trajectory of the pedicle screws and the anatomy of the bony surface. The depth of the screws and the trajectory were kept in 3D format, the surface of which was the inverse of the posterior vertebral surface, to ensure accurate screws insertion. The diameter and length of the cylinders were measured by Mimics. The basic models of screws were rotationally drawn by command of Pro/E, and the internal diameters and lengths were adjusted so as to meet the size of cylinders, such as, the diameter of screw heads equals the sum of internal diameter and the height of screw thread. The screw head was completed by command of “mix/notch”, and outputted by the format of *.STL.

3-Dimensional Printing

These designed models can be printed in 3D by Fused Deposition Modeling (FDM), the parameters of which are: 0.4-mm diameter nozzles, with setting of layer thickness of 400 µm, referred to as vertical resolution, default values of 25% infill and 1-mm shell thickness, and filament of 1.75 mm in standard size. This desktop-grade printer caters to educational entities with resolution of 300 µm typically. The models were then input by Flash Print, where frail spots were inspected and adjusted by view, as shown in Figure 1, and where some parameters were set to a Tree-like support structure. All models were added to print at a proportion of 1: 1 by Cura with a BT600 3D printer. The navigator was printed with plastics materials, while screws were made of steel.

Results

Surgical Application

By following these aforementioned designs, the patient-specific template was subsequently manufactured by a 3DP system.
with photosensitive resin material after manipulation following a 6-step procedure: (1) spinal model rebuilt: to rebuild a spinal model taken by the 3DP system; (2) drill trajectory searched: to search the way for the trajectory manually; (3) navigational pathway through: the pathways were passed through for navigation; (4) nail way preplanned: to preplan for nail way, ensuring precision; (5) navigating frame made: where navigating frames were made by 3DP; and (6) pathway with frame combined by then a template was combined by pathway and frame for drilling. The navigational template was designed computationally, as shown in Figure 2, and a screw was designed, as shown in Figure 3. The resulting products are tolerant to gamma radiation, stable against hydrolysis, and suitable for sterilization without deformation [18]. After being sterilized for 4 h with glutaraldehyde steam, according to the regulations for sterilizing instruments, these printed solid products

![Figure 1. Printing parameters. Created by Mimics, ProEngineering, and Fused Deposition Modeling.](image1)

![Figure 2. Processes of navigator. (A) Spinal model built; (B) drill trajectory planned; (C) navigational pathway through; (D) nail way preplanned; (E) navigational frame made; (F) drill template combined. Created by Mimics, ProEngineering, and Fused Deposition Modeling.](image2)
can pliably guide the internal fixation onto the spine successfully, as demonstrated in Figure 4.

Clinical Testing

The drilling cannulas are columns available for the drill bit to pass through, with a 2.5-mm inner diameter and a 4.5-mm outer diameter. Pilot holes were drilled on a full-scale spinal model, with the template mounted on the spine. Trajectories were guided by cannulas, which were set so that the direction and size were predefined for predesigned screws to pass through securely without misplacement or being too big or too small to fit, and the routes were directly visible. The direction was fixed until the optimized screw path was found to ensure that the virtual cylindrical implant was entirely inside the bony structure but did not penetrate the walls of the pedicle. Observed from 2D iconography in sagittal, transverse, and coronal planes post-operationally, as demonstrated in Figure 4, it was confirmed that the implant was intraosseous, and the purpose of clinical testing was targeted. Given a range of sizes for implants, including parameters such as angles, lengths, heights, and widths, the spinal equipment will be utilized in patients with patho-anatomical deformation and will facilitate the identification of “hidden” anatomic anomalies invisible on conventional radiography, while minimizing complications, such as stress-shielding and implant migration. This 3DP drill template enables trialing of screw installation and identification of diameter, length, and trajectory preoperatively, iatrogenically mitigates the risks of neurovascular injury, and reduces any probability of encountering unexpected anatomy relative to structures positioning [19,10]. It is convenient for surgeons to perform this approach manually rather than using fluoroscopy-assisted or free-hand techniques [11,22]. This approach resulted in less pedicle penetration and screw misplacement; therefore, the patient demonstrated rapid recovery, which serves to advocate for future implementation. This use of 3DP is a potential method to realize individualized operation accurately and is a viable alternative in intraoperative navigation.

Patient Feedback and Education

We presented a demonstration of the percutaneous operation for initial patient guidance, which included sterilization and placement of models in the operative theater, spatial orientation, and explanation of specific situations, to acquire informed consent. The patient could visualize the surgical procedure, which contributed to the understanding of the patient’s disease, and counseling was provided while reviewing...
the patient’s own anatomy. This procedure distracts a patient from pain, overcomes phobias, reduces anxiety, helps the patient make more educated decisions, and even motivates the patient to make lifestyle changes.

The patient reported appreciation for this technology and substantial compliance after reviewing these 3DP models. Furthermore, our surgical interns were allowed to discuss within multidisciplinary teams, to perform these intraoperative navigations, to educate themselves of the correct procedures before entering the clinical setting, and to promote hands-on experiences similar to those of attending classes on campus, which facilitated excellent teaching effects.

Discussion

Surgical Planning

Generally, biomodels created by appropriate software are the basis for precise results. As a medical processor for imaging and 3D editable software, the reconstructive function of Mimics is instructive for interns to study anatomy, because the interns can learn the process of designing the navigator, to select the best nail point and screw angle. Also, an authentic Mimics preoperative 3DP module is practical for interns to emulate the operation, get information for internal fixation of the pedicle screw, rehearse in vitro procedures, and predict intraoperative problems encountered, which realizes the objective of “practice substitution for teaching”. This simulative teaching pattern is especially helpful to overcome steep learning curves in trainee education through mock surgical procedures, to develop independence from experience, and to ease operative difficulties. Biomodels are adopted for up-to-date surgical teaching and anatomical training purposes, allowing the flexible design of geometric and material properties to be simulated in clinical scenarios without cost barriers and the associated ethical and anatomic variation present in cadaveric studies. Patel et al indicated that “72 articles describing simulation-based training courses were either validated or had a translational outcome, [and] these results were categorized into transphenoidal surgery and training courses” [23]. By contrast, Pucci et al found some limitations in their review [24]. 3DP biomodels play important roles in the training of surgeons by illuminating the architecture of the spine and intricate anatomy that is difficult to emulate by alternative modalities. With models in hand, surgeons could evaluate operative details in a realistic way for young residents to experience spinal surgery. The preoperative overview of 3D models enables surgeons to anticipate intraoperative difficulties, choose an optimized method, visualize the screw trajectory, plan implant placement, and access essential special equipment. Biomodels widen applications in preoperative workflow, enabling surgeons to be uniquely acquainted with the anatomic complexity of the presenting case by visualization and tactile manipulation of replication. Furthermore, the concept of 4-dimensional modeling is to add 3DP with a parameter of ‘time’ in order to visualize how components interact in motion, which is a tool to train novice surgeons to comprehend the quality learning curve. Finally, these models can be shown to patients before surgery for patient education about the selection of appropriate locations and optimal osteosynthesis. For the patient, a solid model is easier to understand than is a complex MRI or CT scan. D’Urso et al reported increased patient informed consent with 3D models than with image demonstration [25]. Currently, the precision for template by Mimics is deficient; however, with the development of software and upgrades of hardware, its precision will be improved greatly.

Application of 3DP

Basically, the individualized 3DP patient-specific template generated from biomodels optimizes accurate implantation. In terms of 3DP, first of all, it is known as an additive manufacture, geometrically promoting the potential of applications to assist procedural accuracy and surgical planning, enabling physical realization of virtual CAD models. 3DP is a rapidly expanding industry and is defined as the third revolution in the design and printing of surgical templates for the complex anatomy of the spine. It is essential because of the delicate nature of the surrounding structures. Its mechanism is to translate spine CT scans into a 3DP guide or template, and its segmenting process permits translation from medical images to virtual models consisting of a dataset for the specific extracted structure. Current spinal 3DP applications comprise 4 interesting topics: (1) implantable devices, such as vertebral body replacement, interbody fusion cages, and implants for disc replacement, (2) surgical instrumentation, such as screw guide templates, (3) surgical preplan and training, such as models of vertebral segments, and (4) tissue engineering, such as scaffolds for cartilage regeneration. Regarding specific examples, Provaggi et al stated “while a wide range of 3DP [are] explored in anatomical models for the medical setting, their applications are cutting-edge in the field of spinal surgery” [26]. Other applications in orthopedics include external customized fixators to assist trauma reduction, which outperform conventional surgery in orthopedic trauma and plastic surgery. On this basis, the introduction of individualized patient-specific implants is a priority in spinal surgery, and 3DP appears to be a valuable solution [27]. FDM is currently the most popular printing technology worldwide because it is affordable, there are various machine types that are easy to acquire by interns in spinal surgery, it fulfills miscellaneous demands, and its principle is to heat a filiform-like hot melt that deposes onto a designed panel based on the predetermined
trajectory, slice by slice, and the physical products are printed layer upon layer [28-31]. The merits of FDM also include being secure and clean, without chemical toxicity or pollution. In addition, the operative plans can be created in 3D template production to allow surgeons to accurately guide the depth and direction of the trajectories and determine the distance and angle. According to Mizutani et al, biomodels permit us to optimize the placement of intraoperative hardware in surgery in advance, especially in cases of complex anatomical scoliosis and pathologies. Studies have reported that the virtual surgery using models results in the safe placement of screws in complicated cases [32-34].

Moreover, 3DP is meaningful in tailoring patient-specific prostheses and in creating and finishing the surface exactly, also with a manipulated porosity that aids osteointegration. It allows the fabrication of various structures and surfaces, permitting the printing of complex structures, such as lattices, it enables medical devices to specifically design feature pores or topologies “in growth” to encourage osseointegrative bonding strength to devices, and contributes to rapid recovery [35,36].

3DP of individualized artificial cartilage scaffolds or 3D bio-plantations can preserve anatomy during implantation, shorten operative time, require fewer dissections, lessen the risk of neurovascular compromise, and improve the stability of construction, thus, truly achieving minimally invasive surgery, without excessive removal of surrounding structures. Patient-specific sockets can also be made by using the 3DP technique for a customized rehabilitation solution after amputation of the lower limb extremity, which is anatomical in strength and durability [44]. Due to the requirement of traditional internal fixation and open reduction, the extensive exposure of deep structures increases the incidence of infectious diseases and slows wound healing. For spinal surgeons, the accuracy of the placement of the pedicle screw remains our concern, because it has been reported that misplacement occurs in more than 20% of cases [45,46]. Because free-hand screw implantation is heavily dependent on surgical experience, screws inserted with standard techniques often penetrate the bony outer wall or even miss the pedicle. Trajectories and drill templates must be optimized prior to surgery. 3DP improves the placement of biologics or hardware in compressed spaces under limited visibility, as Bandyopadhyay et al reported in 2020 [47]. 3DP screws placed in the pedicle and laminar by 3DP guides have shown superior precision, with less perforation of the pedicle cortex and fluoroscopic frequency than traditional placement. Specific examples of such applications include the navigation of variable anatomy, minimization of incision size, and patient-specific instrumentation in conjunction with optimized trajectories, without invasive exposures [48-50].

Our intraoperative method made many clinical advancements. In particular, there were many patterns for the design of an individualized navigational model, such as the percutaneous template with minimally invasive surgery and the point connective template based on the signalized index on the body surface [51,52]. Our experimental templates were designed basically by an intraoperative method, which is similar to traditional

Collaborative Biomodels

Additionally, 3DP is a manner of collaborating biomodels, providing visual and tactile clarity to lessen adverse outcomes. 3DP biomodeling translates 2D images into patient-specific anatomic models. Patient-specific screw guide templates are based on patients’ individualized CT data, reverse engineering, computational software, and 3DP techniques. Customized implants can be produced to match individual anatomies, orthoses, and prosthetics, and are safely inserted with small incisions. For example, Hu and Lin succeed in assisting percutaneous vertebroplasty with templates in 2019 [42]. In 2018, Li et al described an external template to install iliosacral screws [43]. By visualizing morphology, surgeons will select a bony surface that the template can be firmly attached as an entry point, to enhance surgeons’ knowledge of patho-anatomy, and to achieve precise implant placement. Patient-specific instrumentations can preserve anatomy during implantation, shorten operative time, require fewer dissections, lessen the risk of neurovascular compromise, and improve the stability of construction, thus, truly achieving minimally invasive surgery, without excessive removal of surrounding structures. Patient-specific sockets can also be made by using the 3DP technique for a customized rehabilitation solution after amputation of the lower limb extremity, which is anatomical in strength and durability [44]. Due to the requirement of traditional internal fixation and open reduction, the extensive exposure of deep structures increases the incidence of infectious diseases and slows wound healing. For spinal surgeons, the accuracy of the placement of the pedicle screw remains our concern, because it has been reported that misplacement occurs in more than 20% of cases [45,46]. Because free-hand screw implantation is heavily dependent on surgical experience, screws inserted with standard techniques often penetrate the bony outer wall or even miss the pedicle. Trajectories and drill templates must be optimized prior to surgery. 3DP improves the placement of biologics or hardware in compressed spaces under limited visibility, as Bandyopadhyay et al reported in 2020 [47]. 3DP screws placed in the pedicle and laminar by 3DP guides have shown superior precision, with less perforation of the pedicle cortex and fluoroscopic frequency than traditional placement. Specific examples of such applications include the navigation of variable anatomy, minimization of incision size, and patient-specific instrumentation in conjunction with optimized trajectories, without invasive exposures [48-50].

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fixation for the pedicle implant. We utilized the biomodel to anatomically examine variations between patients, optimized the angle of insertion preoperatively for percutaneous tubular retractors, and delineated the size of bony spaces and location to reduce damage of adjacent bones, muscles, and tendons. With the assistance of individualized navigation, the amount of bleeding was reduced. The most attention must be paid to the fact that the degree of precision depends on the degree of template fit to the bigger spine, that is, in the larger area of the spine connecting to the template, the closer the fit, the more precise is implantation. However, the larger area suggests more invasion of soft tissue; therefore, a practical condition must be considered prior to surgery. The preparation and visualization afforded by individual models is clinically beneficial in facilitating teammate communication, compared with that of conventional imaging. Alignment of visual landmarks identified through biomodels and minimization of fluoroscopies identified through haptic cues reduce the risks of ionizing radiation, prolonged anesthesia, and infection, and will provide superior precision in placement of pedicle screws, compared with free-hand or fluoroscopy-guided techniques. It is helpful postoperatively for the evaluation of anatomic restoration regardless of its limitations, such as being time-consuming to design, unacceptable to medical insurance, having lower resolution that normal tissue, having warping and shrinkage of surfaces, and poor strength and durability. According to Zhang et al in 2023, in some cases, it is also anatomically helpful for making correct diagnoses, where it is not otherwise obvious, and for preplanning subsequent procedures [53]. The apparent limitation of biomodels is histocompatibility, due to material that is incompatible to the human body. Another potential effect on the clinical application is that surgeons must account for impeding soft tissue, because if patient-specific instrumentation does not fit well, a false sense of certainty can arise. To overcome this, it is important to be aware if a cutting block cannot be positioned properly. We are sure these drawbacks will be overcome with the development of upgraded software and the evolution of 3DP. This specific area of biomaterial science should be explored in further research. A practical recommendation for routine practice is to build a 3DP laboratory for each spinal department, when the cost is acceptable to the average hospital.

Training Applications

Finally, our specific teaching drill experiment presented effective tutorials for surgical interns. The delivery of medical education has changed with technological advancement – from a chalk-board to a slide-based presentation becoming a popular option among educators around the world for decades due to its small learning curve and the ability to place instructors in lecturing mode. Slide-based lecturing allows lecture material to be organized into slides for presentation that includes various effects, such as sounds, animation, colors, and graphs, to keep courses interesting. Its downside, due to an overwhelming number of slides, includes the lack of interactive learning due to passive learning with a negative effect on student performance. Historically, lecture-based curricula generally encourage passive engagement, namely, a teacher-centered approach in which teachers deliver information, and students acquire knowledge without conscious effort. This approach is inexpensive and produced quickly; however, it does not stimulate critical thinking or active learning [54]. In recent years, other teaching modalities, such as 3DP anatomical models, augmented reality, and virtual reality simulation, have been explored to augment educational experience, as a machine learning-powered tutorial platform for trainees to practice and perfect surgical skills preoperatively. Simulation is at the forefront of modern education, and our study showed that novice learners were confident in completing the simulated tasks. Active learning in emulation is a student-centered approach, with conscious effort in assigned activities. However, haptic feedback is likely to be an integral part of the simulator, whereby trainee satisfaction and loyalty will increase with enthusiasm. In the clinic, 3DP models are more cost efficient than cadavers. The widespread use of tutorials is also affordable, and its patient-specific guide is more intuitive in supporting equivalent accuracy with less time needed for teaching spinal surgery. These training programs focus on enhancing surgical skills in a patient-free environment; the advantages of box-trainer training (also called video trainer, incorporating automated auditory and video-based instruction specific to the resection domain) over simulation training include (1) lower cost, which could train multiple trainees simultaneously in short courses; and (2) better realism, emulative training appears to shorten operating time and optimize operative performance of surgical trainees with limited laparoscopic experience, compared with box-trainer training. Those with intermediate experience and proficiency will not benefit significantly from simulator training, while novice performance was improved in operating rooms after completing proficiency-based tutorial programs during resident education. Many areas of medicine benefit from visualization and interaction through numerous training applications and pedagogy, as He et al stated in 2019 [55]. The greatest advantage of stereoscopy is the immersive visualization, intuition, exploration, and navigation during training and planning of image-guided therapy that can be used by instructors to drive annotations and movements that occur without explicit command. Active-learning simulation consists of active thinking, strengthens problem-solving skills, and even builds student empathy for patients prior to interaction. We illustrated scenarios such as intervention training and personalized education for interns, which were functional for navigating and manipulating the clinical scene. “Guide on the side” teaching is readily seen in active-learning pedagogies, such as problem-based learning and team-based...
learning, which are popular, as evidenced by universities specifically in healthcare education. Both problem-based learning and team-based learning have shown benefits by promoting communication, teamwork, and creativity; these pedagogies often tutor theory not applied in real-world scenarios, which is called “practical substitution for teaching”.

Conclusions

We successfully produced our individualized navigator for spinal surgery to guide internal fixation pliably to the spine. Abstracted from the experimental outcome, the individualized navigator for spinal operation is considered to be more convenient for surgeons than free-hand techniques. There are 3 main findings of this study: (1) Biomodels are the basis of navigative precision, while 3DP is unimportant. Even if 3DP optimizes accurate implantation, it is just a copy of biomodels that enable surgeons to depict anatomic complexity by visualization and manipulation; (2) patient-specific instrumentation is an individualized and viable alternative in intraoperative navigation; and (3) this simulative teaching pattern is helpful to overcome steep learning curves in trainee education. With the application of the 3DP navigational template for pedicle screw installation, patients reported their appreciation, and surgical interns were instructed to perform individualized navigation precisely. To summarize, this fostering a style of “replacing practice for teaching” is an up-to-date paradigm and is meaningful not only for clinical surgery but also for medical training; thus, it is worthy of recommendation.

Declaration of Figures’ Authenticity

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