Cadaveric Spinal Surgery Simulation: A Comparison of Cadaver Types

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Abstract

Study Design Single-blinded study.

Objective To assess the suitability of three types of cadaver for simulating pedicle screw insertion and establish if there is an ideal.

Methods Three types of cadaver—Thiel-embalmed, Crosado-embalmed, and formaldehyde-embalmed—were draped and the spines exposed. Experienced surgeons were asked to place pedicle screws in each cadaver and give written questionnaire feedback using a modified Likert scale. Soft tissue and bony properties were assessed, along with the role of simulation in spinal surgery training.

Results The Thiel cadaver rated highest for soft tissue feel and appearance with a median score of 6 for both (range 2 to 7). The Crosado cadaver rated highest for bony feel, with a median score of 6 (range 2 to 7). The formaldehyde cadaver rated lowest for all categories with median scores of 2, 2.5, and 3.5, respectively. All surgeons felt pedicle screw insertion should be learned in a simulated setting using human cadavers.

Conclusion Thiel and Crosado cadavers both offered lifelike simulation of pedicle screw insertion, with each having advantages depending on whether the focus is on soft tissue approach or technical aspects of bony screw insertion. Both cadaver types offer the advantage of long life span, unlike fresh frozen tissue, which means cadavers can be used multiple times, thus reducing the costs.

Keywords
- Thiel
- Crosado
- simulation
- pedicle screw
- cadaver

Introduction

Spinal pedicle screw insertion is common but technically difficult[1,2]; it has a recognized learning curve and potentially significant complications.[1–3] Pedicle screws are used in all types of spinal surgery for deformity correction, tumor decompression and stabilization, fracture stabilization, and fusion surgery for degenerative disease. Screw insertion can be done freehand or using X-ray; freehand screw insertion is equally safe in trained hands.[4] The complications of screw insertion are rare but can include nerve root injury, spinal cord injury, vascular injury, and abdominal/thoracic injury.[3] Simulation training in surgery means the procedures can be learned in a safe environment.

Methods have been described for computer simulation of pedicle screw insertion,[5] but these methods are limited to teaching the theoretical aspects of screw insertion and do not address feel, which is a vital part of judging correct screw placement. Sawbones (Pacific Research Laboratories, Vashon Island, Washington, United States) can be used, which will

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allow familiarization with the instrumentation and the sequence of events involved in instrumenting the pedicle. The feel and technical difficulty of Sawbones does not resemble live surgery, though. There is a logical argument that learning an incorrect feel for procedures that rely heavily on haptic feedback intraoperatively may be counterproductive and dangerous, but there is no research on this contention in any surgical field.

Cadaveric tissue offers lifelike anatomical simulation for technical procedures but formaldehyde-preserved cadavers have stiff tissues. It is difficult to identify soft tissue planes, limiting their use for the simulation of surgery. The University of Leeds has recently started producing cadavers preserved with the Thiel embalming process that are known to have better soft tissue properties.[6]

In this study, we compared three types of human cadavers to establish if any of them offers a realistic reproduction of screw insertion in live surgery and if there is an ideal cadaver type on which to train.

Materials and Methods

Three types of human cadaver were assessed: Thiel-preserved, Crosado-preserved, and formaldehyde-preserved. Fresh frozen tissue was not assessed, as it is not currently used in our department. The cadavers were assessed during a spinal surgery course taught on Thiel cadavers. Thiel cadavers have only recently become available in Leeds, and there is no published work establishing the suitability of Thiel cadavers for training in spinal surgery, although the suitability for other surgical disciplines has been described in plastic surgery,[6,7] maxillofacial surgery,[8] cardiac surgery,[9] general surgery,[10] and urology.[11]

Formaldehyde- or "formalin"-preserved cadavers are usually preserved using an arterial injection technique, and the fluid used for anatomical education embalming contains 37 to 39% formalin. The fluid is injected under pressure and can then be drained from the venous system or left in situ. One of the reasons for the exploration of alternative embalming techniques has been a concern over the potential health risks of the high levels of formaldehyde. Crosado embalming also involves the injection of embalming fluid but the fluid uses a much lower concentration of formalin, typically around 2%. Thiel embalming is also based on an initial perfusion followed by immersion for at least 2 months in embalming fluid, following which the bodies can be stored either in plastic bags or submerged in the fluid. Thiel embalming fluid also contains very low amounts of formaldehyde.

One cadaver of each type was positioned prone and the spine exposed from C7 to S1 by the lead author (J.E.T.), using a posterior approach. Sharp dissection was used, and the spine was exposed as far laterally as the transverse processes to ensure all study participants had a clear view of the relevant anatomy. Cadavers were draped to leave only the spine exposed, thereby blinding study participants to cadaver type, and were labeled A (Thiel), B (formaldehyde), or C (Crosado). All surgeons placed two screws in each cadaver and gave immediate written questionnaire feedback.

The 10 study participants were all senior spine fellows or consultants with a range of experience in spinal surgery from 2 to 20 years and a mean of 9.5 years. The Stryker Xia 3 pedicle screw system was used (Stryker, Kalamazoo, Michigan, United States), and all screws placed were 6.5×45 mm.

The participants assessed the cadavers using a modified Likert scale, with 7 points from completely disagree to completely agree. Participants were asked to rate the soft tissue and bony properties of each cadaver with regards to appearance and feel and whether they were an accurate reproduction of live tissue/surgery. Questions were also asked on the role of simulation in spinal surgery and whether pedicle screw insertion should be learned in live surgery or in a simulated setting.

The participants were also asked to rate the various forms of simulation available for spinal surgery. The following types of simulation were graded: computer model without haptic feedback, computer model with haptic feedback, Sawbone models, animal cadavers, and human cadavers. Each one was marked on a visual scale of 1 to 10, where 1 = poor and 10 = excellent.

Results

Cadaver A (Thiel) was rated most realistic for soft tissue appearance and feel with median scores of 6 for both categories (range 2 to 7), and cadaver C (Crosado) was rated most realistic for bone feel with a median score of 6 (range 2 to 7). Cadaver B (formaldehyde) was rated poorly for all three categories with median scores of 2 for soft tissue feel, 2.5 for soft tissue appearance, and 3.5 for bone feel (ranges 1 to 6, 2 to 5, and 2 to 5, respectively). The results are shown in ►**Table 1**.

The broad range of scores for all categories should be noted; even though all participants were experienced in spinal surgery, there was a lack of agreement between the surgeons. The responses were not affected by experience in spinal surgery; there was a lack of uniformity in response even in those participants with the greatest experience.

Table 1 Cadaver type with Likert scores for soft tissue appearance, soft tissue feel, and bone feel

Cadaver type	Soft tissue appearance, median (range)	Soft tissue feel, median (range)	Bone feel, median (range)
Thiel	6 (2–7)	5.5 (2–7)	4 (2–6)
Formaldehyde	2 (1–6)	2.5 (2–5)	3.5 (2–5)
Crosado	4.5 (2–6)	4 (2–6)	6 (2–7)

Although the differences were seen between the median scores as shown in ►**Table 1**, they did not reach statistical significance. Kruskal-Wallis one-way analysis of variance showed *p* values of 0.381 for soft tissue appearance, 0.451 for bone feel, and 0.669 for soft tissue feel.

There was strong support for pedicle screw insertion being learned in a simulated environment for the first time, which is not currently the case within United Kingdom training schemes and indeed is not universal policy anywhere in the world at the present time. The median score for “Should screw insertion be learned in a simulated environment?” was 7 (range 6 to 7), with a median score of 3 (range 1 to 4) for “Screw insertion is safe to learn in live surgery.”

All those surveyed felt anatomy and tissue appearance and feel should all be reproduced as accurately as possible if learning screw insertion in a simulated setting. Several participants also made informal comments that cadaveric simulation plays a useful role even when highly experienced, as it allows a far greater exploration of the surrounding anatomy than would normally be possible when doing a procedure on a patient. Feedback on the simulation types currently or potentially available was also taken, and the results are shown in ►**Table 2**. The table shows human cadavers were rated most strongly for simulation of pedicle screw insertion because they provide realistic anatomical appearance and re-create feel most accurately. Free text comments indicated that many respondents felt that Sawbone simulation is useful to develop familiarity with the instrumentation and knowledge of the technique but less so for the actual technicalities of the procedure due to the lack of soft tissues and the feel being slightly unrealistic. There was once again a broad range in responses for all types of simulation except human cadavers and a lack of uniform agreement as to the ideal simulation type.

Discussion

Our results support the use of both Thiel and Crosado cadavers for teaching pedicle screw insertion. Thiel cadavers were felt to have a more realistic soft tissue feel and appearance, but Crosado cadavers were felt to have more realistic bony properties with better representation of the feedback experienced when placing screws during live surgery. Formaldehyde cadavers were rated poorly for soft tissue feel, soft tissue appearance, and bony feel and are therefore not ideal for teaching pedicle screw insertion. There was strong support for pedicle screw insertion to be learned in a simulated environment, with all participants scoring 6 or 7 to the question “Should pedicle screw insertion be learned in a simulated environment for the first time?” It was also felt that human cadavers are the ideal way to do this task, with cadavers scoring the highest in the assessment of the different simulation methods.

Table 2 Simulation type versus suitability for training (1 = lowest score, 10 = highest score)

Simulation type	Median score (range)
Computer model (no haptics)	2 (1–6)
Computer model (haptics)	5 (1–7)
Sawbone model	5 (2–8)
Animal cadaver	6 (1–9)
Human cadaver	9 (8–10)

Screw insertion was deliberately assessed using feel despite that it is subjective, as we wanted to reproduce screw placement in live surgery as accurately as possible. Freehand screw placement in live surgery relies on feel (haptic feedback) from the pedicle finder, the probe, and also the feedback when placing the screw itself. Torque measurement does not play a role when inserting screws during surgery, and thus torque measurement was not used in this study. It is not used in training and it is difficult to define normal values for insertion torque, so a useful comparison is difficult. It was not possible to fully dissect the cadavers used in this study to assess for pedicle breaches as the cadavers were preserved for further educational use. All screws were removed and their trajectories thoroughly probed for any evidence of breach, however.

Bergeson et al and Gonzalvo et al showed that inexperienced surgeons need to place up to 80 screws before screw placement becomes accurate, with few pedicle breaches.[1,2] Given that pedicle breach carries the risk of potentially significant complications, it is an ideal technique to learn in a simulated setting. The questions of how many screws should be placed in a simulated setting and how to assess technique were not addressed in this work. Simulating screw insertion would allow mistakes to be made in an environment that carries no risk to patient safety. It is arguable that deliberate mistakes should be encouraged in the simulated setting so that the feel for both correct and incorrect placement, which is vital in freehand screw insertion, can be developed. If trainees can develop muscle memory for the feel of both correctly and incorrectly placed screws, then insertion will be performed more safely in live surgery. However, it is not current practice in most units to learn pedicle screw technique in a simulated setting—screws are often placed for the first time in live surgery.

The strengths of this study are that it is the first of its kind comparing cadaver types using surgeons blinded to tissue type to eliminate bias. All surgeons taking part in the study were highly experienced, with a mean of 9.5 years' experience in spinal surgery (minimum 2 years), and have placed large numbers of pedicle screws in live surgery. All the cadaveric spines were exposed by a single surgeon who did not participate in the assessment of the cadavers to remove bias to tissue type. Each surgeon compared the cadavers in sequence to allow accurate comparison between the three types, and surgeons were not allowed to discuss their findings with other participants until they had completed their feedback questionnaires. Feedback was given after instrumenting each cadaver to prevent reliance on recall memory.

The limitations of this study are that despite efforts to blind surgeons to cadaver type, there are some visual differences between tissue types that cannot be eliminated and are thus a potential source of bias. Formaldehyde-preserved tissues also have a characteristic smell, which may also act as a source of bias. The bone mass density of each cadaver was unknown, which may potentially impact on the bone quality in each cadaver, although the cadavers were all from donors between 80 and 85 years of age and of similar body habitus. There is currently no published work on the effect of embalming with different preservation fluids on the bone density.

The differences seen between the cadavers did not reach statistical significance, which may be due to the relatively small numbers in this study. In addition, there was significant variation in scores between the surgeons, the reasons for which are not clear in this small study.

This study supports the use of simulation in spinal surgery for learning to insert pedicle screws, and human cadavers offer the most realistic simulation with accurate reproduction of anatomy, appearance, and feel. Thiel and Crosado cadavers both rated highly for their tissue properties, with Thiel having the most realistic soft tissue properties and Crosado having more realistic bony properties. Formaldehyde cadavers were poor for both soft tissue and bony properties, and although having the advantage of a long life span and relatively low cost, they are not recommended for surgical training.

Fresh frozen tissue is often used for surgical training courses but has a limited life span of only 48 to 72 hours, unlike Thiel and Crosado cadavers that can potentially be kept for several years. Fresh frozen tissue thus remains an expensive option due to the need to use fresh tissue each time particular skills are taught. The long life span of both Thiel and Crosado cadavers means a single cadaver can be used for multiple surgical procedures and potentially shared between different surgical specialties. There is work published on the use of Thiel cadavers in plastic surgery,[6,7] maxillofacial surgery,[8] and cardiac surgery,[9] although the use of Thiel cadavers remains limited outside the German-speaking countries.[12] Thiel bodies can be used for radiology training in imaging-guided biopsy techniques and also for regional anesthesia techniques.[13,14] It is important to acknowledge that each level of a spine can only be instrumented once, meaning reuse for pedicle screw insertion is limited, but with careful coordination of training across specialties, multiple uses of each cadaver across several months or years should be possible.

Conclusion

This study supports the use of human cadavers for training in spinal surgery using both Thiel and Crosado cadavers. Both cadaver types are potentially suitable for this task, with each offering slight advantages over formaldehyde preservation for soft tissue or bony properties while offering a long life span and thus reusability and greater economy over fresh frozen tissue. Thiel cadavers can also be used for training in other surgical specialties and wider specialties,[7–9,13,14] but they are not currently known about or used widely with the exception of Austria, Switzerland, and Germany, where their use is more common.[12] Through cross-specialty collaboration, this extremely useful resource may be exploited more widely, with better distribution of the costs of providing this excellent training resource.

Cadaveric simulation provides the ideal environment to learn spinal and other surgery techniques but will have significant cost implications if adopted as the gold standard for training.

A wider philosophical and economical debate must now take place as to whether these costs can be overcome by training schemes. Although the cost of providing cadaveric tissue and facilities for training is potentially significant, it is debatable whether we should continue to teach screw insertion in live surgery, especially when there is published evidence of a long learning curve. A wider debate among the surgical educational community must now take place about the role of cadaveric simulation in training going forward. A larger-scale study comparing cadaveric and noncadaveric training techniques in spinal surgery is now needed.

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