Surgical Technique

Comparison of standard and modified prone positioning for lateral lumbar spine fusion: a feasibility study to reduce lumbar plexus injury

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Abstract: Single-prone-lateral (PL) positioning is a new technique that allows for simultaneous anterior and posterior lumbar spine surgery. However, there is a concern regarding the risk of lumbar plexus injury in PL positioning. This study compared the risk of lumbar plexus damage and the overall safety profile of a modified PL (mPL) position to the standard PL (sPL) position for lateral lumbar spine fusion surgery. A crossover soft cadaveric study was conducted with two raters examining the comparative outcomes of position A: sPL and position B: mPL. The mPL position differs from the sPL position in that the ipsilateral arm is placed at the side of the body rather than above the head. To assess positive results (no lumbar plexus injury) between positions A and B, a mixed effects logistic regression model was utilized. The odds ratio of a good result between positions B and A was also determined. The odds ratio of the favorable outcome between position B and A was 1.77, indicating significantly higher odds of a favorable outcome in the modified position B than in the control or position A. The mPL positioning outperformed the sPL positioning in terms of safety and efficacy for lateral lumbar spine fusion. The mPL positioning may reduce the risk of lumbar plexus injury by allowing for a more direct approach to the lumbar spine and by avoiding excessive stretching of the lumbar plexus.

Keywords: Standard prone-lateral position (sPL position); modified prone-lateral position (mPL position); lateral lumbar spine fusion; cadaveric study

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Introduction

Lateral lumbar interbody fusion (LLIF) is a well-known and minimally invasive surgical procedure used to treat a variety of degenerative lumbar spine conditions. Direct access to the intervertebral disc via the psoas muscle lying posterior to the retroperitoneum requires only a small incision. Several studies have demonstrated various clinical advantages of the LLIF technique including (I) larger cage placement as compared to anterior or posterior interbody fusion approaches (1-3), which aids in; (II) restoration of lordosis by correcting disc sagittal alignment, foraminal height and other coronal deformities in the thoracolumbar spine (1,2,4-7); (III) reduced damage to the posterior paraspinal muscles resulting in less blood loss, postoperative

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pain/trauma, and quick recovery time (2,6,8,9); (IV) positive patient outcomes (9,10); and (V) reduced morbidity, making it a safer, reproducible, and more stable biomechanical environment for arthrodesis (7,9,11). However, the LLIF approach, first described by Ozgur [2006] (8), had a logistical drawback in that it required the patient to be in a lateral decubitus position, followed by prone positioning for interbody access and percutaneous screw placement. The multiple patient positions during the surgery resulted in increased operative time, healthcare costs, and resource utilization while decreasing overall procedure efficiency (12-14). As a result, surgeons have recently expressed an interest in pursuing single-position lumbar interbody fusion procedures (15). In the past few years, single-position prone-lateral (PL) surgery has emerged as a part of the evolution and gained popularity. Lamartina and Berjano pioneered prone positioning, reporting successful implantation in seven patients across seven levels of the spine. In addition to providing access to the anterior, prone positioning allows the surgeons to perform posterior techniques, such as direct decompression and fusion (prone transpsoas technique). It improves navigation and makes accurate screw placement easier, which is highly recommended for improving patient stability, restoring lordosis, and lowering nonunion rates (16-18). Although prone transpsoas positioning (PTP) has been shown to be safe and effective (16), it is not without significant risks. Firstly, prone position does not allow access to L5–S1 anterior column (19). Furthermore, other potential complications of prone surgical positioning, such as hemodynamic changes leading to hypoperfusion and cardiovascular disorders, various ophthalmologic conditions including perioperative visual loss (POVL), and a range of neurological and myocutaneous complications (20-27), may result in the patient's permanent disability. Moreover, injury to the nerves of the plexus due to the insertion and dilation of dilators and retractors remain a significant challenge of all the lateral interbody fusion approaches, leading to increased morbidity (2,5,28). According to a study by Grunert *et al.* (28), approximately 50% of plexus nerve injuries occurred at the segments L1–L4, after lateral fusion procedures in the spine, also involving the sensory and motor nerves. Considering the current trend toward value-based healthcare, consideration of alternative forms of surgical techniques that reduce operative times while maintaining patient safety and surgical outcomes merits further investigation. Therefore, we designed a modified version of the standard prone positioning for investigating its feasibility for lateral lumbar spine surgery using a cadaveric model. In this present study, the raters attempted to determine the evidence of the guide wire piercing or injure the nerve root, the second rater dissected the guide wire and checked for nerve root injury after the first rater inserted it. So, there were four options to consider: (I) nerve root damage obviously with guide wire penetration; (II) nerve root was close to the guide wire; (III) the guide wire was distance from the nerve root; and (IV) the rater could not identify a relationship between the location of the nerve root and the guide wire. The present study was undertaken with the objective to explore and compare the likelihood of lumbar plexus injury between standard prone positioning and modified prone positioning, facilitating single-point access to lumbar fusion. We present this article in accordance with the SUPER reporting checklist (available at https://jss.amegroups.com/article/view/10.21037/jss-23-92/rc).

Highlight box

Surgical highlights
- Direct access to the intervertebral disc.
- Restoration of disc height and lordosis.
- Modified prone-lateral (mPL) with intraoperative neuromonitoring is associated with a lower risk of lumbar plexus nerve injury.

What is conventional and what is novel/modified?
- Conventional lateral lumbar interbody fusion (LLIF): multiple patient positioning during surgery, leading to increased operative time, costs, and resource utilization, and decreased efficiency.
- mPL: patient positioned in modified prone position, initially elevated to 45 degrees, then returned to normal prone position.
- Advantages of mPL: less disruptive to patient's anatomy; may reduce risk of lumbar plexus injury; may shorten operative time.

What is the implication, and what should change now?
- Safer and more efficient way to perform LLIF surgery.
- Reduce risk of lumbar plexus injury, improve surgeon's access to intervertebral disc, and shorten operative time.
- Could become the standard of care for LLIF surgery.
- To shorten operative time in patients with multiple levels fused.

Preoperative preparations and requirements

This was a cross-over study conducted from Jan 2023 to March 2023. A total of nine soft adult cadaveric human specimens (n=5 males and n=4 females) were calculated with the equation as shown and studied to compare the feasibility of standard PL (sPL) and modified PL (mPL) positioning for lumbar spine fusion.

$$n = \frac{\left(z_{1-\frac{\alpha}{2}} + z_{1-\beta}\right)^2 \sigma^2}{\Delta^2} \quad [1]$$

Study parameters: α=0.05, β=20%, Δ=5.0, σ=4.4, power =0.80.

The statistical formula used in the study is a logistic regression model to analyze data where there are both fixed and random effects. In this case, the fixed effect is the positioning technique (modified versus standard), and the random effect is the cadaver. The model is used to estimate the odds of a favorable outcome (no lumbar plexus damage) in the modified positioning technique compared to the standard positioning technique. The comparative outcomes of both types of positioning were investigated by two raters. The cadavers were chosen based on inclusion and exclusion criteria. Both male and female cadavers were above the age of 18 years and had no spinal or abdominal surgery. *Table 1* lists the inclusion and exclusion criteria for enrolling cadavers in this study. The study was conducted in accordance with the Declaration of Helsinki (as revised in 2013). The Institutional Ethics Committee of the Faculty of Medicine Ramathibodi Hospital, Mahidol University granted ethical approval (No. COA. MURA2020/395) and informed consent was taken from all the family members or surrogates before cadaveric donation.

Table 1 Inclusion and exclusion criteria for enrolling cadavers in the study

Inclusion criteria
Both male and female genders
Age: >18 years
Exclusion criteria
Cadavers who had spinal surgery or abdominal surgery

Step-by-step description

Positioning and surgical technique

Each cadaveric specimen's right and left sides were randomly assigned to either (A) control or sPL position, or (B) sample or mPL position. The sPL position (*Figure 1A*) is described by inserting a guide wire under fluoroscopy. To reach the desired intervertebral level (L2–3, L3–4, and L4–5), the guide wire was punctured parallel to the floor thereby targeting the Kambin's triangle as figured. In the newly mPL position, the cadaver was initially elevated to 45 degrees. Under fluoroscopic guidance, one of the raters inserted the guide wire parallel to the floor in the cadaver's lumbar spine up to the desired intervertebral level (L2–3, L3–4, and L4–5), thereby targeting the Kambin's triangle in both A and B positions. The cadaver was then returned to its normal prone position while the target was fixed (*Figure 1B*). Finally, for the neurosurgeon to approach the target, the guide wire was leveled (*Figure 2*). Following the insertion of a guide wire in both positions (A and B), the cadavers

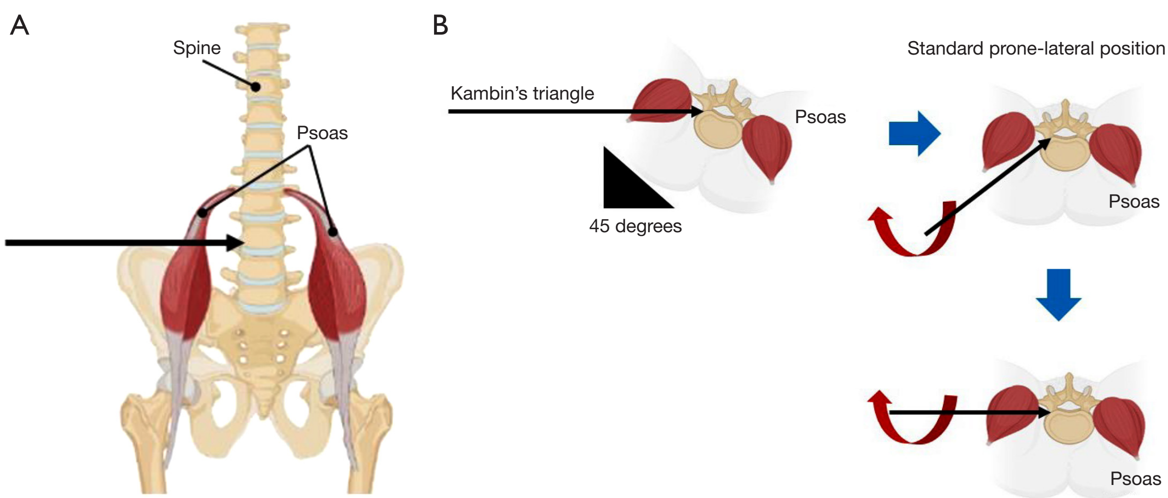

Figure 1 The figures show the cadaver's position in the standard and modified prone-lateral positions. (A) Standard prone-lateral positioning. (B) Modified prone-lateral position.

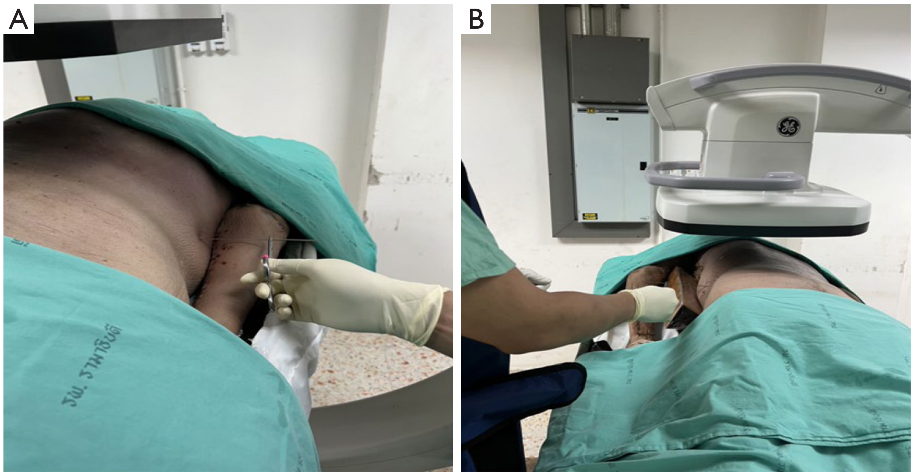

Figure 2 Insertion of the guide wire in the cadaver in both (A) the standard prone-lateral and (B) modified prone-lateral positions.

Table 2 Percentage outcome agreement between the two raters

Agreement outcome	Agreement (%)	Expected agreement (%)	Cohen's kappa (κ)	Standard error	P
Favorable outcome	83.33	73.58	0.3691	0.1486	0.0065
Unfavorable outcome	91.84	62.93	0.7798	0.1420	<0.001

were examined for any lumbar plexus injury in the psoas muscle. Agreement between the two raters for any favorable (guide wire was at a distance from the lumbar plexus and no nerve root injury occurred) and/or unfavorable (guide wire pierced the lumbar plexus and nerve root injury occurred) outcomes after the guide wire insertion were determined. The comparative outcome of the two positions A and B were studied to assess the superiority of one position over the other for the lateral lumbar spine fusion approach.

Statistical analysis

The collected data were analyzed with the STATA program (StataCorp. 2021. Stata Statistical Software: Release 17. College Station, TX: StataCorp LLC). Continuous and categorical variables were summarized using mean (standard deviation) and frequency (%), respectively. Interrater agreement was assessed by kappa for categorical variable and assessed by 95% (Bland and Altman) limits of agreement (LOA) for continuous variable. The comparison of favorable outcomes between positions A and B was performed by mixed effects logistic regression model. The odds ratio of the favorable outcomes between positions B and A was also estimated. The significance level was set at P<0.05. The description of the research design includes:

- Each cadaver is used in both mPL and sPL postures.
- To avoid bias, the process sequence is randomized.
- Following each technique, two raters examine the cadavers to check whether there is any lumbar plexus damage. A statistical model is used to evaluate the two positioning processes and determine which one is more likely to have a positive outcome (no lumbar plexus injury).

Results

Analysis of the outcome agreement between the two raters

A statistically significant agreement of 83.33% (κ=0.3691; P=0.0065) was observed between the two raters regarding the favorable outcome (that the guide wire was at a distance from the lumbar plexus and no nerve root injury occurred) in both positions A and B. Similarly, a statistically significant agreement of 91.84% (κ=0.7798; P<0.001) was observed between the two raters regarding the unfavorable outcome (that the guide wire pierced the lumbar plexus and nerve root injury occurred) in both positions. The details of the agreement analyses have been given in *Table 2*.

Table 3 Concordance correlation coefficient estimate between the outcome measures of the two raters

Variables	Values
Difference (SD)	2.957 (6.856)
95% LOA	−10.481, 16.394
Correlation between difference and mean	−0.501
B-BF test (P value)	5.366 (0.01486)

SD, standard deviation; LOA, limits of agreement; B-BF, Bradley-Blackwood F.

Table 4 Logistic regression estimates of the favorable outcome between positions A and B

Modified prone-lateral position	Odds ratio of position B versus position A	Standard error	Z	P	95% confidence interval
Favorable outcome	1.77	1.60	0.63	0.527	0.30–10.45

Concordance estimate analysis

The concordance estimate analysis has been given in *Table 3*. The data showed no concordance between the outcome measures of the two raters.

Logistic regression analysis

The odds ratio of the favorable outcome between positions B and A was 1.77 as given in *Table 4*.

Postoperative considerations and tasks

The perioperative and postoperative procedures and considerations for lateral lumbar spine fusion are similar to those for other types of spine surgery. There are, however, a few points to clinical concern:

- ❖ During the procedure, the patient will be put in a PL posture. This may be painful for some people; thus, sufficient pain management is essential.
- ❖ Because the patient is at risk for pressure sores while practicing, it is crucial to cushion all pressure points and move the patient on a regular basis.
- ❖ Postoperatively, the patient will be unable to sit or stand for several weeks following surgery. This is done to allow the spine to properly fuse. Following surgery, the patient may have discomfort and stiffness. These symptoms can be managed with pain medication and physical therapy. In addition, the patient should be informed the following: (I) how to treat their wound; (II) how to avoid pressure sores; (III) how to move safely following surgery; (IV) when should the patient seek medical attention?

Tips and pearls

Preoperative: select patients who are suitable candidates for LLIF surgery with care. Patients with degenerative lumbar spine diseases such as spinal stenosis, spondylolisthesis, and disc herniation are included. A complete preoperative history and physical examination should be obtained. This will aid in the identification of any possible hazards or consequences. Order imaging investigations such as X-rays, magnetic resonance imaging (MRI), and computed tomography (CT) scans if needed. This will aid in the planning of the operation and the identification of any potential anatomical problems.

Intraoperative: to reduce the chance of problems, use an intraoperative neuromonitoring (IONM) and precise surgical procedure. Take cautious not to injure the lumbar plexus nerves with IONM. To obtain the desired surgical outcome, use a range of implants. Cages, screws, and rods may be included.

Postoperative: provide sufficient pain management postoperatively. Looking for indicators of problems, such as infection, bleeding, or neurological abnormalities. Educate the patient about wound care, pressure sore prevention, safe movement following surgery, and when to seek medical assistance.

Use a patient positioning system built specifically for LLIF surgery. This will aid in keeping the patient safe and comfortable during the procedure. To guide the placement of the implants, use a fluoroscopy system. This will aid in ensuring precise insertion and reducing the possibility of problems. Consider using robotic surgical technology with IONM. Robotic surgery with IOMN can enhance accuracy and precision while also lowering the risk of complications. In addition, work with an experienced team of surgeons and nurses. This will aid in ensuring that the procedure is carried out safely and effectively.

Discussion

The primary finding of this novel study is that the newly mPL positioning (position B) is superior to the sPL positioning (position A) for lumbar spine fusion. Good

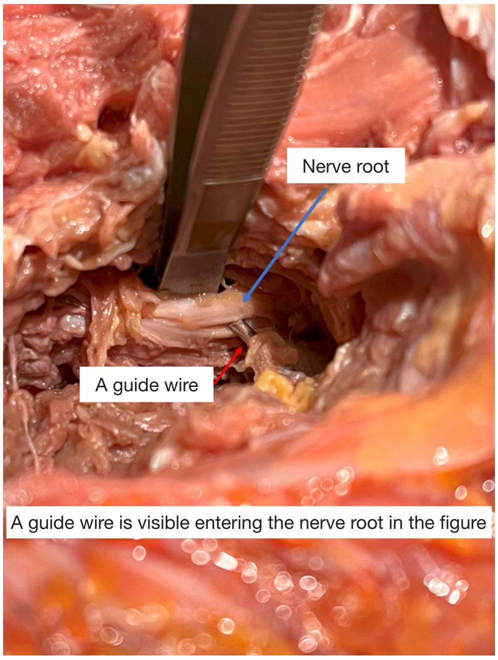

Figure 3 A guide wire is visible entering the nerve root in the figure.

outcome or favorable outcome would be no nerve root damage and a successful fusion method. Bad outcome or unfavorable outcome would be nerve root damage and a failed fusion method. The two raters in this study objectively decide the measured results. For example, the two raters concluded that the cadavers should be examined for signs of nerve root damage, such as nerve piercing or contacting. Since the raters attempted to figure out the evidence of guide wire piecing the nerve root, thus after the first rater placed the guide wire, the second rater dissected it and looked for nerve root injury. So, there were four options: (I) nerve root injury clearly with guide wire penetration in *Figure 3*; (II) nerve root was touching the guide wire closely; (III) the guide wire was distance from the nerve root; and (IV) the rater could not find the relationship between the location of the nerve root and guide wire.

In the current study, the interrater agreement was 83.33% (κ=0.3691) for a favorable outcome (no nerve root injury) and 91.84% (κ=0.7798) for an unfavorable outcome (nerve root injury occurred) in both A and B positions. However, there was no concordance between the outcome measures of the two raters when assessed by 95% (Bland and Altman) LOA (−10.481, 16.394). PTP is a relatively new approach with several advantages (29), such as (I) well-acquainted and secured patient positioning without requiring complex repositioning; (II) increased capacity for lordotic correction via induced gravity while prone; (III) minimally invasive approach with a lower risk profile than other fusion techniques; and (IV) access to a wider disc space for larger cage placement, improved sagittal alignment, and lordotic angling (30). Furthermore, previous research on the PL approach has yielded promising results. In a randomized study, Lamartina and Berajo (17) compared seven patients undergoing lateral interbody fusion in a prone position and 10 in the lateral decubitus position. They found that the PL group had a shorter operative time and similar back and leg Numerical Rating Scales (NRSs) at follow-up. Farber *et al.* (31) demonstrated in a case series that the single-position PL transpsoas approach resulted in successful treatment for adult patients (n=29), with well-tolerated and acceptable clinical and radiographic outcomes. Barkay *et al.* (32) assessed their experience with the traditional PL interbody fusion technique that was previously described by Pimenta *et al.* (15). The most common complication experienced by patients (45%) was hip flexor pain on the ipsilateral side. There were only two cases (2.4%) of postoperative femoral nerve palsy, both of which disappeared spontaneously after 3 months (32). Monitoring the locations or the distances from the exiting nerve root and trunks (within the psoas muscle) to the guide wire during the minimally invasive lateral lumbar spine fusion surgery may be critical to avoid injury to intrapsoas nerves and increase the safety of the transpsoas approach. In a cadaveric investigation, based on a lateral radiograph, Park *et al.* (33) discovered that the nerve trunk was at a mean of 14.0±5.9 mm posterior and at a mean of 5 mm closer to the center of the disc than the exited nerve. According to a study by Pimenta *et al.* (15), the psoas muscle and lumbar plexus were more posteriorly located in the prone position versus both supine and lateral decubitus, with the hip significantly extended in prone. In a similar study by Alluri *et al.* (34), the femoral nerve within the lumbar plexus was discovered to be 10% or more posteriorly located at the L4–L5 disc space in the prone position, creating a larger safe zone and reducing the risk of neurologic complications in the prone versus lateral decubitus position. Nevertheless, imaging results from research by Amaral *et al.* (35) did not corroborate the idea that, in the prone position, an extension of the hips would cause the lumbar plexus nerves to shift posteriorly. Therefore, in our current study, the cadavers were examined for any lumbar plexus injury in the psoas muscle, following the insertion of guide wires in the lumbar spine (at L2–3, L3–4, and L4–5 levels) in both

A and B positions. We observed no lumbar plexus injury in either A or B positions. However, the odds ratio of the favorable outcome between positions B and A was found to be 1.77, indicating that the intervention or modified position B was associated with a higher likelihood of a favorable outcome than control or position A. This is the first study demonstrating an improved safety profile with a significantly better outcome (the guide wire was at a distance from the lumbar plexus and no nerve root injury occurred) using our mPL positioning than the previously established prone positioning (or sPL) for lateral lumbar spine fusion approach. The study's first goal is to show the practicality of the mPL, particularly in the normal spinal alignment, with the goal of eventually using it in clinical settings. The mPL positioning approach, after a learning curve, might be used in clinical settings for lateral lumbar spine fusion in a number of patient demographics, including those with degenerative spondylolisthesis, spinal stenosis, and spondylodiscitis. It may be especially beneficial for patients with complex lumbar pathologies, such as lumbar rotation or scoliosis, because the mPL positioning may allow for better access to the surgical site and more precise instrumentation placement with IONM.

Limitations

Even though this is a soft cadaveric study, the main limitation of this study is that it was conducted on cadaveric specimens which may not be applicable to living patients. Additionally, the sample size was relatively small, and it seems there is only one level of lumbar spine fusion surgery was studied. Further research with larger sample sizes and multiple levels should be conducted to confirm these findings in a clinical setting. There was no radiological evaluation in the study. This is a limitation of the study, as it would be valuable to assess the mPL positioning technique's impact on postoperative radiographic outcomes, such as pedicle screw placement, foraminal decompression, and spinal alignment.

Conclusions

The preliminary findings from this soft cadaveric study suggested that our mPL positioning offers a feasible, effective, and safe approach for minimally invasive spinal fusion. However, additional clinical investigations are needed to confirm its reproducibility and define patient outcomes for efficient surgical solutions.

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Footnote

Reporting Checklist: The authors have completed the SUPER reporting checklist. Available at https://jss.amegroups.com/article/view/10.21037/jss-23-92/rc

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Conflicts of Interest: Both authors have completed the ICMJE uniform disclosure form (available at https://jss.amegroups.com/article/view/10.21037/jss-23-92/coif). The authors have no conflicts of interest to declare.

Ethical Statement: The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. The study was conducted in accordance with the Declaration of Helsinki (as revised in 2013). The Institutional Ethics Committee of the Faculty of Medicine Ramathibodi Hospital, Mahidol University granted ethical approval (No. COA. MURA2020/395) and informed consent was taken from all the family members or surrogates before cadaveric donation.

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