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RESEARCH ARTICLE

# Computed Tomographic Analysis of the Anatomical Parameters of the Ideal Screw Trajectory Line for Laminar Screw Fixation of the Lumbar Isthmus

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**ABSTRACT**

**Objective:** Assessment of laminar anatomical parameters required for rigid fixation of the lumbar isthmus with intralaminar screws using computed tomography (CT).

**Materials and Methods:** Retrospective lumbar CT scans of 36 adult patients were analyzed. The parameters of the ideal laminar screw trajectory line required for isthmic defect fixation were determined using 3D multiplanar reconstruction, and linear and angular parameters were measured. The laminar screw length (LSL), the width of the thinnest part of the lamina (LW), the transverse distance of the screw entry into the lamina relative to the midline (TD), sagittal (SA) and coronal (CA) screw application angles were evaluated bilaterally at all lumbar levels.

**Results:** The mean age of the patients was 22 years. The LSL had similar values at the levels L1–3 (35–36 mm), with a slight decrease at L4 and L5 (33–32 mm). The LW increased from L1 to L4 (7–9 mm), with a slight decrease observed at L5 (8 mm). The TD increased steadily from L1 to L5 (56–10 mm). The SA was similar at L1–3 (23°–25°), with a marked increase toward L4 and L5 (30°–40°). The CA increased consistently from L1 to L5 (6°–20°).

**Conclusion:** For rigid intralaminar screw fixation, optimal angular and linear screw application parameters should be carefully reviewed in preoperative CT studies to increase the laminar cortical bone attachment of the screw and prevent potential neurologic injury.

**Keywords:** Intralaminar screw, isthmic fixation, laminar screw, lumbar CT scan, posterior neural arch spondylolysis

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## INTRODUCTION

The isthmus (or pars interarticularis) is located between the inferior and superior articular processes, and lamina and is the most sensitive part of the posterior neural arch at the junction of these three bony structures.[1–4] It is accepted that repetitive hyperextension and flexion microtraumas create structural stress in the isthmus. Isthmic defects develop in genetically predisposed individuals in particular, and this condition is called spondylolysis.[1,5–9] Whether the defect develops suddenly or gradually, and the exact mechanism involved, remains unclear. The defect is mostly bilateral and occurs most frequently (80% prevalence) at the L5 level, with a 10% prevalence at L4, and a gradually decreasing frequency at the more upper levels.[3,7,8] In the general population, isthmic defects are seen in 5%–10% of the population, although this varies by race and level of participation in competitive sports.[3,6,8,10] Conservative treatment is the gold standard for isthmic defects.[2,3,10–13] Multiple surgical techniques are available, ranging from segmental fusion to direct or indirect repair of the defect in patients who remain symptomatic despite all conservative treatment methods. There is currently no consensus on the gold standard method of surgery, and the decision regarding the preferred option is made by the surgeon and the patient.[13–16] Rigid fixation of

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the isthmic defect with intralaminar screws is performed in adolescents and young adults in particular when the intervertebral disc is healthy and the pars injection is positive.[3,17]

Buck reported a 90% clinical success rate for isthmic defect fusion with an iliac bone graft and intralaminar screw with open surgery, and this rate currently varies between 60% and 100%.[3,11,18] Intralaminar screw fixation of the isthmic defect is inherently low profile and motion segment sparing and provides restoration of the disrupted posterior neural bone arch.[2,3,14]

Despite the widespread use of minimally invasive techniques and robotic surgery, anatomical studies to facilitate the application of the lumbar intralaminar screw are limited.[1,5] The aim of this study was therefore to analyze lumbar computed tomography (CT) scans in young adults to determine the linear and angular anatomical parameters at all the lumbar levels for the ideal trajectory of the laminar screw for isthmic defect fixation.

## MATERIALS and METHODS

### Ethical Declarations

The study protocol was approved by Istanbul Medipol University institution's ethics committee (date: 28.05.2024, no: E-10840098-202.3.02-3210). The study was conducted by the principles of the Declaration of Helsinki.

### Study Population

The parameters were analyzed by a single observer at three different times.

We retrospectively analyzed 36 consecutive young patients with equal gender distribution, who presented with low back or leg pain and had normal lumbar CT scans. The mean age of the patients was 22 years (18–33). The mean age of the men was 21±5 years and 22±4 years for the women. Each CT scan was performed with the patient in the supine and neutral position, with 2 mm sections through the anatomical areas of interest. Patients with trauma, infection, scoliosis, spina bifida, metabolic bone disease, spondylolisthesis, inadequate or incomplete images, patients who had undergone surgery, and patients with developmental abnormalities of the facet joint were excluded.

### Measured Anatomical Parameters

Lumbar CT scans were acquired on a Centricity Universal Viewer Version 7.0 (GE Healthcare, Chicago [IL], United States) radiology imaging workstation for free adjustment of the variable gantry angle, and the ideal screw trajectory was determined by three-dimensional (3D) multiplanar reconstruction (Fig. 1). The following parameters were then measured at the ideal screw trajectory to include the most bone tissue between the inferolateral part of the lamina and the pedicle:

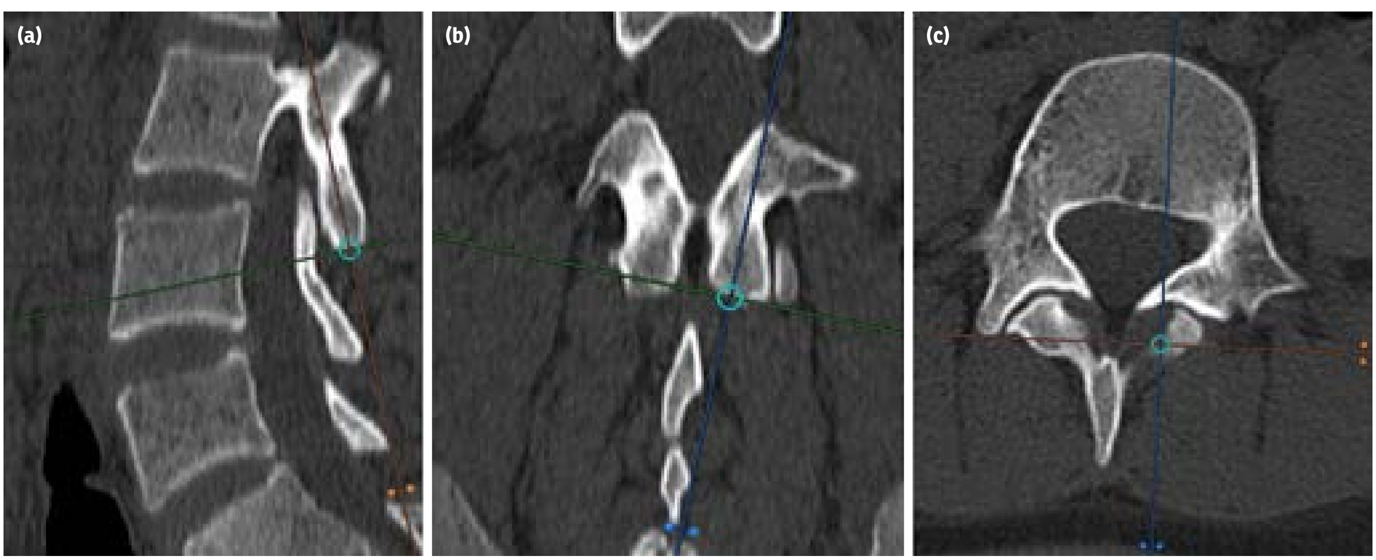


**Figure 1.** Laminar screw trajectory detected by real-time manipulation in the sagittal, coronal, and axial windows with 3-dimensional (3D) multiplanar reconstruction on lumbar computed tomography imaging in the supine position. In the sagittal **(a)** and coronal **(b)** planes, the vertical line through the lamina, pars neck, and pedicle shows the intralaminar screw trajectory. In the axial plane **(c)**, the intersection of the axis line with the lamina indicates the screw entrance point

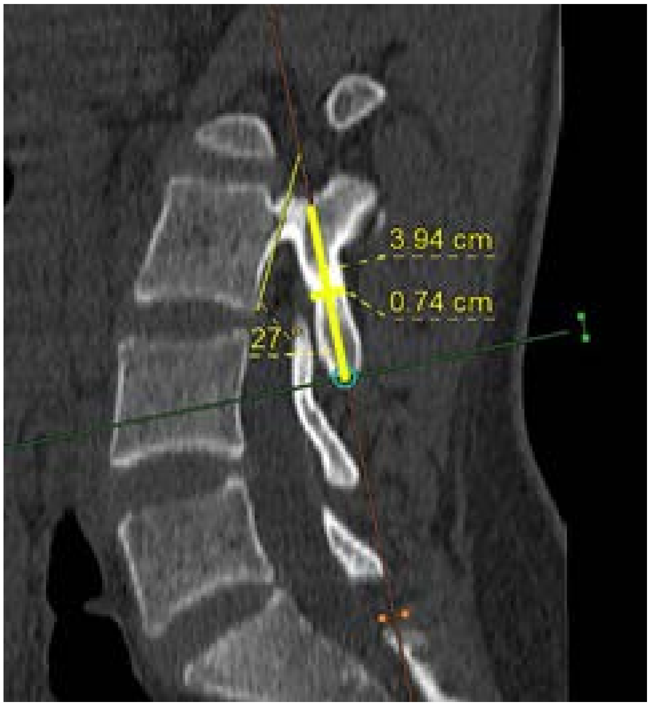


**Figure 2.** Sagittal plane image, the sagittal angle of the screw trajectory line relative to the posterior cortex of the vertebral body is 27°, the screw length is 3.94 cm, and the width of the narrowest part of the lamina is 0.74 cm

- Maximal laminar screw length (LSL): the maximum screw distance starting from the inferolateral part of the lamina near the facet joint, through the intralaminar region, the pars defect area, the defective pars neck, the pedicle, and finally ending at the inner border of the pedicle superior cortex (Fig. 2).
- Width of the narrowest part of the lamina (LW): the width between the outer cortices of the narrowest part of the lamina at the ideal screw trajectory (Fig. 2).
- Distance of the screw entry into the lamina relative to the midline (TD): the distance of the screw entry into the lamina relative to the vertebral midline in the axial plane Figure 3.
- Sagittal screw angle (SA): the sagittal angulation of the screw trajectory line relative to the posterior cortex of the vertebral corpus in the sagittal CT plane (Fig. 2).
- Coronal screw angle (CA): coronal angulation of the screw trajectory line relative to the midline on the coronal CT plane (Fig. 4).

The parameters were analyzed by a single observer at three different times.

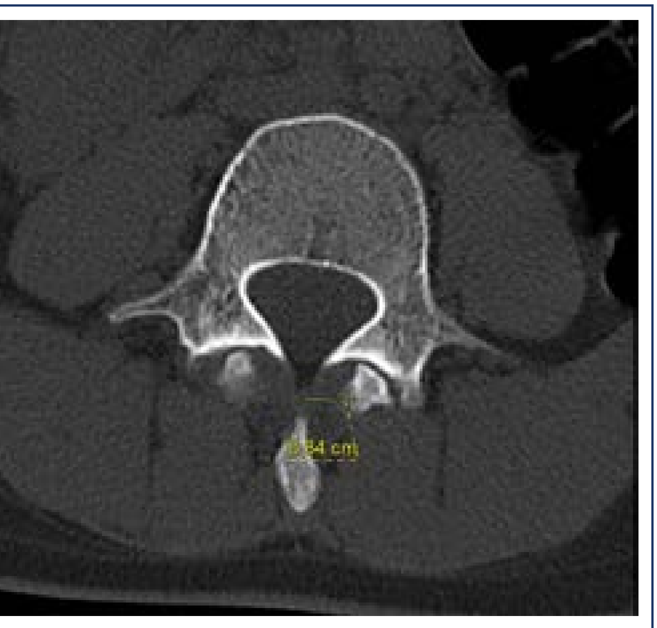

**Figure 3.** Axial plane image, the transverse plane distance of the screw entry point into the lamina relative to the midline


**Figure 4.** Coronal plane image, the coronal angle of the screw trajectory line relative to the corpus midline is 5°

Table 1. Mean (standard deviation) and range of laminar screw parameters

| Lumbar levels | Maximal laminar screw length (mm) | | Width of the thinnest part of the lamina (mm) | | Transverse distance from the midline to the screw entry point in the lamina (mm) | | Sagittal angle (°) | | Coronal angle (°) | |
|---|---|---|---|---|---|---|---|---|---|---|
| L1 | 34 (3) | 29–41 | 7 (1) | 5–11 | 6 (1) | 4–7 | 23 (3) | 17–28 | 6(1) | 4–8 |
| L2 | 34 (2) | 32–38 | 7 (1) | 5–10 | 6 (1) | 5–7 | 24 (2) | 20–29 | 6(1) | 4–9 |
| L3 | 35 (2) | 32–39 | 8 (1) | 5–12 | 7 (1) | 5–8 | 25 (2) | 19–28 | 9 (1) | 7–12 |
| L4 | 33 (2) | 30–36 | 9 (1) | 6–11 | 8 (1) | 5–9 | 30 (3) | 23–37 | 14(1) | 11–16 |
| L5 | 32 (3) | 25–38 | 8 (1) | 6–12 | 10 (1) | 7–12 | 40 (5) | 32–53 | 20 (3) | 12–26 |

Table 2. Results from correlation analysis (Pearson) of the variables

| | Lumbar level | LSL | LW | TD | SA | CA |
|---|---|---|---|---|---|---|
| Lumbar level | 1.00 | | | | | |
| Maximal laminar screw length (LSL) (mm) | -0.36 | 1.00 | | | | |
| Width of the thinnest part of the lamina (mm) (LW) | 0.32 | -0.06 | 1.00 | | | |
| Transverse distance from the midline to the screw entry point in the lamina (mm) (TD) | **0.78** | -0.38 | 0.26 | 1.00 | | |
| Sagittal angle (°) (SA) | **0.81** | -0.40 | 0.14 | **0.75** | 1.00 | |
| Coronal angle (°) (CA) | **0.90** | -0.44 | 0.24 | **0.79** | **0.82** | 1.00 |

R- values ara provided with statisticallly significant ($p<0.05$ ) in bold. LSL: Maximal laminar screw length; LW: Width of the thinnest part of the lamina; TD: Transverse entry distance of the screw relative to the midline; SA: Sagittal angle; CA: Coronal angle

### Statistical Analysis

All the parameters were measured 3 times at 1-week intervals by the author, who has experience with intralaminar screws. The mean of the 3 observations was used in all the statistical evaluations to minimize intra-observer variation. Pearson correlation analysis was used to investigate the relationships between the variables and the vertebral levels. The analysis of the various parameters between the vertebral levels was conducted using the ANOVA test, and the differences between the 2 sides and gender were analyzed using Student's t-test. The normality of data distribution was assessed using the Shapiro-Wilk test. For normally distributed data, parametric tests were applied, while non-parametric tests were used for data that did not follow a normal distribution. The data were analyzed using SPSS statistical analysis software, version 22.0 (SPSS, Inc., Chicago, IL, USA).

## RESULTS

The intra-observer agreement was excellent, although small differences were found in the 3 observations made for each parameter (mean kappa 0.843). No statistical differences were observed in the measurements by side and gender ($p>0.05$). However, significant variations were found in both linear and angular measurements across all vertebral levels from L1 to L5. The mean LSL ranged from 25 to 46 mm (minimum-maximum), with the longest at L3 (mean 36 mm) and the shortest at L5 (32 mm). The width of the narrowest part of the laminae ranged from 5 to 12 mm, with the widest at L4 (9 mm) and the narrowest at L1 and L2 (6 mm) (Table 1). The screw insertion distance relative to the midline varied between 3 and 14 mm, with the shortest TD at L1 and L2 (5 mm) and the longest at L5 (10 mm). The SA ranged from 15° to 60°, with the highest at L5 (40°) and the lowest at L1 (23°). The coronal angle varied between 3° and 30°, with the highest angulation at L5 (20°) and the lowest at L1 and L2 (6°).

Lumbar levels showed a strong positive correlation with TD, SA, and CA measurements, whereas LSL demonstrated a negative correlation with increasing lumbar levels. These results suggest that TD, SA, and CA values also tend to increase as the lamina level rises, but the LSL value decreases (Table 2).

## DISCUSSION

In patients with spondylolysis, percutaneous intralaminar screw fixation of the isthmus is a low-profile technique that restores the posterior neural arch, preserves the motion segment, and facilitates an early return to active life.[3,11] The

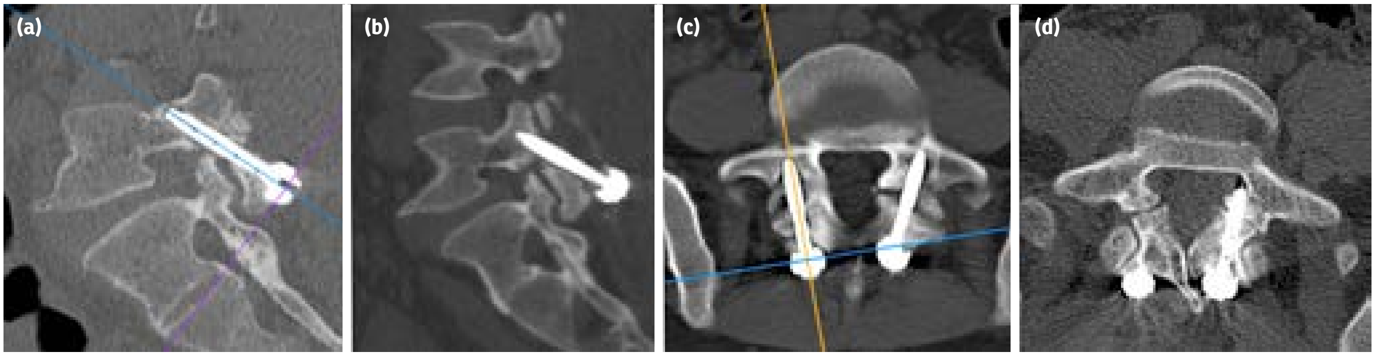


**Figure 5.** 3D multiplanar reconstructions of pars defect screw CT scans. The sagittal plane lumbar CT image shows a pars defect screw with correct bone fixation **(a)** and a screw with incorrect trajectory and inadequate bone fixation **(b)**. The axial plane image shows pars defect screws with ideal trajectory and correct bone fixation **(c)** and a pars defect screw with bone penetration due to incorrect trajectory **(d)**

*CT: Computed tomography*

application of a lumbar laminar isthmic screw is technically challenging and requires 3-dimensional anatomy orientation of the lamina.[3–5,18] Although surgical restoration of the isthmic region with screws has been described previously, laminar morphometric assessments that provide a better understanding of the surgical anatomy are lacking.[1,5,13,16]

In isthmic laminar fixation, the screw entry site begins in the inferolateral aspect of the lamina, close to the inferior articular process. The screw is then directed through the middle of the lamina, isthmus, and pedicle and ends under the superior cortex of the pedicle. Depending on the surgeon's preference, the screw can cover the superior cortex of the pedicle, but further advancement may cause neuronal irritation.[1,5,18] Due to the unique structure of the lamina and its important neural relationship, accurate anatomical knowledge of the posterior neural bony arch significantly reduces the risks associated with screw placement (Fig. 5).

Laminar screw placement is a technically challenging procedure due to its proximity to the nerve roots and spinal cord.[1] Orientation errors may occur even when screws are applied using methods such as fluoroscopy and neuronavigation.[1,2,19,20] Inadequate information and a lack of surgical experience to provide a clear understanding of laminar anatomy and the related risks may play a role in the lesser preference for the laminar screw technique and the development of complications.[1,8,19,21]

A comprehensive feasibility and safety assessment is required for laminar screw application procedures.[3–5,22] Radiologic examinations provide detailed and important anatomic parameters in most cases. Laminar structures may not share a common morphometry at different levels and precisely determining these anatomic variances and knowing the size and angle of the screw application is important in preoperative preparation and the prevention of complications.[1,2,5,22] The intralaminar screw length increases from L5 to L3 and then shortens slightly at L1 and L2. A screw diameter of 3.5–5 mm is preferable, given that the narrowest part of the lamina is a mean of between 6 and 7 mm (minimum–maximum 4–11 mm), to allow some expansion of the lamina during screw placement without causing fracture, as with the pedicular screw.

The indication for isthmic laminar screws is proposed for isthmic defects up to 5 mm. When the angulation of the lamina due to the defect is added, the screw length should be approximately 5 mm longer than from the normal anatomical values we have recommended.[3] Our analysis of the screw sizes discussed in the literature showed that the preferred screw length varies between 3 and 4 cm and the screw diameter between 3 and 5 mm, with the most preferred screw diameter at 4.5 mm.[2,3,13,14,16] At L1–L3, the lamina is thinner, so a smaller diameter screw is required, while the thickest screw can be used at L4. The SA at L5 (40°) and L4 (30°) decreases slightly between L1 and L3 (about 25°), so the SA should slowly be reduced cranially. Since the width of the lamina decreases from L5 to L1, the transverse screw insertion distance is 10 mm at L5 and 6 mm at L1. Likewise, the CA decreases by approximately 14° from L5 to L1 (20° to 6°). A comparison of the laminar screw parameters in spondylolysis with mean laminar screw length values of 36 and 35 mm in L5 and L4 in our study and 32 and 33 mm in L5 and L4 in the healthy lamina in this study, respectively, showed that the measurements were usable in cases with spondylolysis.[1]

Laminar screw application requires comprehensive knowledge of the 3D anatomy of the posterior neural laminar arch, well-planned preoperative preparation, and considerable care during surgery.[3,12,23–25] Complications that may occur during surgery, such as a lack of fixation and nerve root or spinal cord injury, can be very serious. As with the pedicle screw, the use of neuromonitoring with the laminar screw may eliminate the problem of neural irritation. When the isthmic region is targeted with a laminar screw, the screw trajectory is upward, forward, and slightly outward.[1,5,8,18] When the screw is completely intralaminar, the spinal cord and nerve roots are relatively outside the surgical field.[3,9,23] The use of intraoperative 3D fluoroscopy and neuronavigation image guidance improves safety further.[2,19] Fixation of the isthmic defect has been widely studied in the literature, but there are not enough studies demonstrating the feasibility of laminar screws at all lumbar levels.[1,5,26] Pars fixation is recommended for young adults without lumbar disc herniation. As spondylolysis advances to the terminal stage in adults and older adults, the likelihood of successful pars stabilization decreases. This study aimed to evaluate anatomical parameters in young adults.[5,14]

This study may be a guide for feasibility studies of the lumbar isthmic laminar screw. Laminar screw fixation of the isthmic defect requires a rigid screw due to the closer surface relationship of the screw with the cortical bone, and a successful fusion rate of 60%–100 % has been reported.[2,3,11,27] Laminar fixation to reduce or eliminate motion may provide effective fusion because mechanically stable conditions provide the best environment for solid bone union to occur. The potential risks need to be weighed against the expected benefits when selecting the appropriate internal fixation method.

The laminar screw technique with an open technique under semi-direct visualization is easy, and the learning curve is short; spinal canal penetration can be prevented by placing a protective dissector under the lamina during laminar drilling. Although cadaveric study of the laminar region offers a more realistic surgical environment, it has limitations due to availability constraints and strict ethical procedures.

The limitations of this study are that it was not performed on a lamina with spondylolysis, it was not supported by a cadaveric study, ethnic differences were not examined, the evaluation was not performed with multiple observers, and it was performed in a limited series of patients. Further anatomical and radiological studies on the 3D structure of the posterior laminar bone arch are needed for rigid fixation of the lumbar isthmic region with laminar screws and to minimize complications. The results of this study can help surgeons perform safe and accurate placements of lumbar laminar screws and lays the groundwork for future studies.

## CONCLUSION

Laminar screw fixation of the lumbar isthmic region provides the surgeon with an expanded armamentarium as a minimally invasive technique. Due to the highly variable morphology of the lamina, a careful preoperative CT review of the anatomical screw application parameters should be performed for optimal cortical attachment of the screws. According to our radiologic anatomical study, a laminar screw diameter of 3.5–4.5 mm and a screw length of 3.5–4 cm can be used safely.

### Disclosures

**Ethics Committee Approval:** The study was approved by the Istanbul Medipol University Non-interventional Clinical Research Ethics Committee (No: E-10840098-202.3.02-3210, Date: 28/05/2024).

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**Informed Consent:** Written informed consent was obtained from all patients.

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