Radiological Evaluation of Pelvic Morphology for S2 Alar-Iliac Screw Insertion in the Japanese Samples: A Retrospective Cohort Study

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Abstract:

Introduction: S2 alar-iliac screw (S2AIS) insertion for lumbosacral fixation is becoming a common procedure for deformity surgeries. However, studies that have reported the anatomy and morphometric features of the pelvis for S2AIS insertion in the Japanese samples are scarce. This study aimed to elucidate the morphometric features of the pelvis regarding S2AIS insertion in the Japanese samples.

Methods: We used 60 computed tomography scans of the pelvis (30 men and 30 women). The entry point for the S2AIS was determined as 1-mm lateral and 1-mm distal to the S1 dorsal sacral foramen. We resliced the plane in which the pelvis was sectioned obliquely from this entry point to the anterior inferior iliac spine in the sagittal plane. We bilaterally placed the shortest and longest virtual S2AISs in this plane using a 4-mm margin. We analyzed the length, angle, and safety of the determined trajectory and compared these measurements according to sex and age.

Results: The median longest and shortest screw lengths were 108.1 and 103.3 mm, respectively. The median longest and shortest distances from the entry point to the sacroiliac joint were 31.2 and 28.2 mm, respectively. The median smallest and largest lateral angulations were 40.7° and 47.3°, respectively. The median angle range was 4.2°. The median caudal angulation was −2.8°. The median shortest and longest distances from the S2AISs to the acetabular roof were 23.5 and 27.4 mm, respectively. The median distance from the S2AISs to the sciatic notch was 23.1 mm. Assuming the insertion of screw with a diameter of 8 mm, S2AIS insertion was difficult in 32 of 120 (27%) screws because the dorsal cortex of the sacrum was damaged.

Conclusions: Screw length and lateral angulation were similar to those in previous studies. Insertion difficulty occurred in 27% of screws.

Keywords:

sacropelvic fixation, lumbosacral fixation, adult deformity, scoliosis, S2 alar-iliac screw, S2AIS, minimally invasive surgery, degeneration

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Introduction

It has been reported that long fusion to L5 for adult spinal deformity may cause lumbosacral intervertebral disk degeneration and sagittal imbalance[1-4]. Thus, numerous surgeons perform long fusion for lumbosacral lesions. However, lumbosacral fusion has been associated with some complications, such as non-union and implant failure, especially when standalone S1 pedicle screw constructs are used[5,6]. Lumbosacral fusion by using bilateral supplemental

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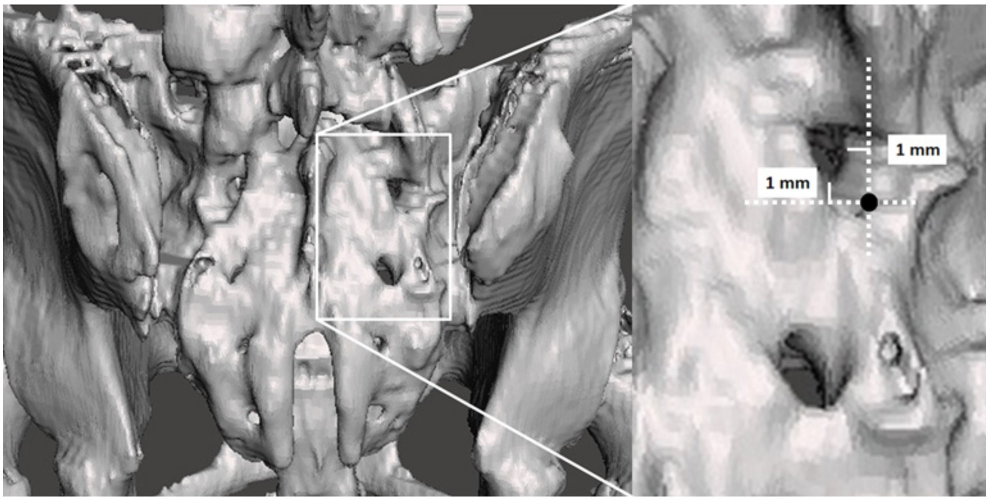

Figure 1. Entry point of the S2 alar-iliac screw (S2AIS) on a three-dimensional computed tomography image. We chose 1-mm distal and 1-mm lateral to the S1 dorsal foramen as the entry point of the S2AIS.

augmentation for S1 pedicle screws resolves such complications. Many studies have demonstrated that spinopelvic fixation for spinal deformities reduces the incidence of pseudarthrosis and implant failure[6-8].

The S2 alar-iliac screw (S2AIS) has become a common implant used in lumbosacral fusion procedures[9] as it resolves several drawbacks of the iliac screw (IS) technique, such as the need for a separate skin incision, symptomatic screw prominence, requirement for offset use, difficult connections with lumbar and sacral screws, and limitations of bone harvesting from the ilium. Similar to the IS, the S2AIS also reduces perioperative complications, such as implant failure and reoperation[10-12]. However, few studies have reported the anatomy and morphometric features of the pelvis for S2AIS insertion in the Japanese population. Previous reports have not investigated the angle range or difficulty of S2AIS insertion[13]. We hypothesized that the morphologic features of the pelvis and parameters of the S2AIS in the Japanese samples would be similar to those reported in previous studies. This study aimed to elucidate the morphometric features of the pelvis for S2AIS insertion in the Japanese samples.

Materials and Methods

This retrospective cohort study was reviewed and approved by our institution's ethics committee, and informed consent was obtained from the patients. We hypothesized that the morphologic features of the pelvis and parameters of the S2AIS in the Japanese samples would be similar to those reported in previous studies.

Computed tomography (CT) data of the pelvis were collected from patients who underwent pelvic CT at our hospital in 2013. A total of 30 CT scans of the pelvis were retrieved. Our study samples consisted of 30 men and 30 women, with an age range of 50 to 79 years. No CT scans indicated bony diseases, osteoarthritis, or spinal deformity, and all were scans of Japanese patients. All CT scans were analyzed using the ZedHip software (Lexi, Tokyo, Japan) and were converted to three-dimensional (3D) models using the same software. We were able to reslice the 3D models in any plane and measure the 3D distance between any two points or between the point and the straight line. All parameters of the 3D models were measured with high accuracy using the aforementioned software.

The entry point (EP) for the S2AIS was determined at 1-mm lateral and 1-mm distal to the S1 dorsal sacral foramen (Fig. 1). We resliced the plane in which the pelvis was sectioned obliquely from this EP to the anterior inferior iliac spine (AIIS) in the sagittal plane. We placed the shortest and longest virtual S2AISs bilaterally in this plane. Furthermore, we used a 4-mm margin for each S2AIS from the inner ilium, outer ilium, anterior sacrum, or posterior sacrum cortex to account for the radius of the screw with a diameter of 8 mm (Fig. 2a-c). We measured 12 parameters of the S2AIS as follows:

1. Screw length (shortest): The screw length of the shortest S2AIS was measured on both sides.
2. Screw length (longest): The screw length of the longest S2AIS was measured on both sides.
3. Distance from the EP to the sacroiliac joint (SIJ) (shortest): The distance from the EP to the SIJ on the trajectory of the shortest S2AIS was measured on both sides.
4. Distance from the EP to the SIJ (longest): The distance from the EP to the SIJ on the trajectory of the longest S2AIS was measured on both sides.
5. Lateral angulation (shortest): The angle to the line of symmetry in the axial plane for the shortest S2AIS was measured on both sides.
6. Lateral angulation (longest): The angle to the line of symmetry in the axial plane for the longest S2AIS was

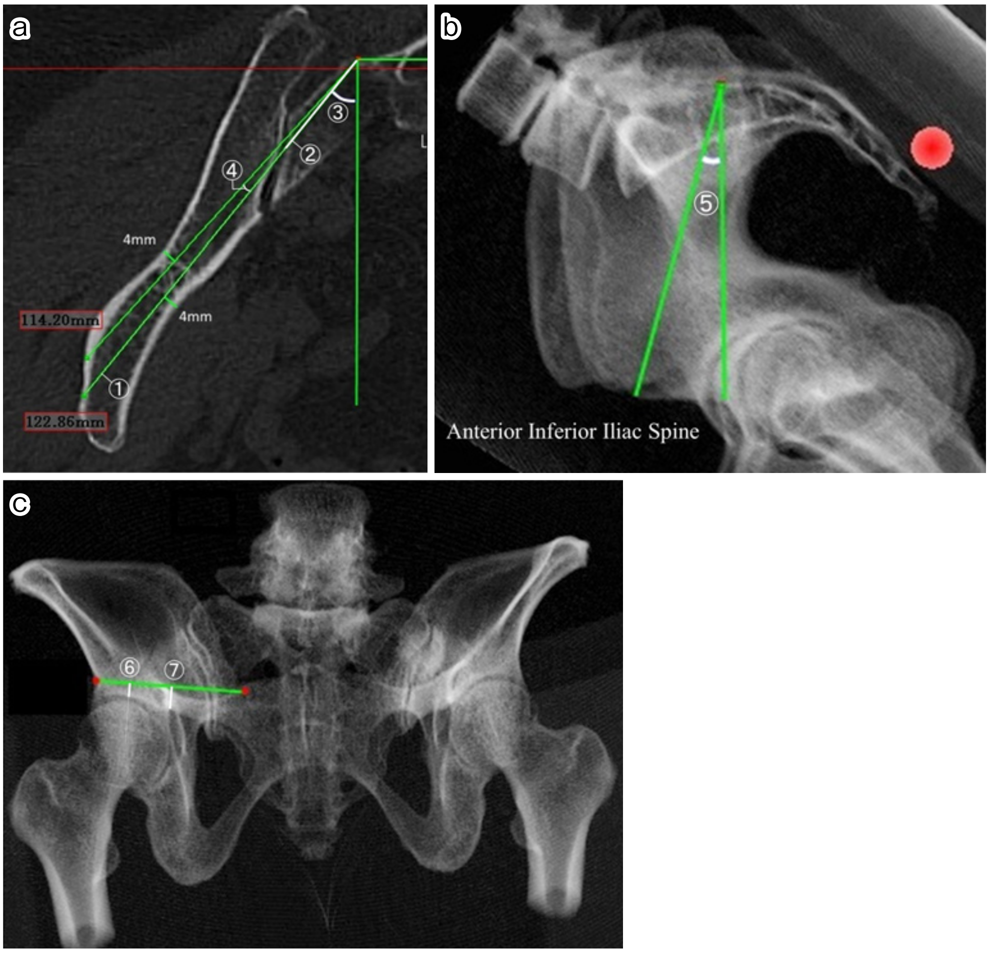

Figure 2. a. Axial plane images along the S2AIS trajectory.
① screw length; ② distance from the entry point to the sacroiliac joint; ③ lateral angulation; ④ angle range.
b. Sagittal plane images along the S2AIS trajectory.
⑤ caudal angulation.
c. Coronal plane images along the S2AIS trajectory.
⑥ distance from the S2AIS to the acetabular roof; ⑦ distance from the S2AIS to the sciatic notch.

measured on both sides.

7. Angle range: The angle between the shortest S2AIS and longest S2AIS was measured on both sides.
8. Caudal angulation: The angle to the line of the S1 endplate in the axial plane for the S2AIS was measured.
9. Distance from the S2AIS to the acetabular roof (shortest): First, we drew a line between the center of the femoral head and the shortest S2AIS. Then, on this line, we measured the 3D distance from the shortest S2AIS to the acetabular roof on both sides.
10. Distance from the S2AIS to the acetabular roof (longest): First, we drew a line between the center of the femoral head and the longest S2AIS. Then, on this line, we measured the 3D distance from the longest S2AIS to the acetabular roof on both sides.
11. Distance from the S2AIS to the sciatic notch: We measured the distance from the S2AIS to the sciatic notch on both sides.
12. Insertion difficulty: We defined insertion difficulty as failure to achieve a sufficient margin.

Statistical analysis

We calculated the median and interquartile range for each parameter and compared each measurement according to sex and age. Insertion difficulty was analyzed using chi-squared test. Other variables were analyzed using the Mann-Whitney U test or Kruskal-Wallis test with the Steel-Dwass *post hoc* test. Statistical analyses were conducted using SPSS version 24.0 (SPSS Japan Inc., an IBM company, Tokyo, Japan) and EZR (Saitama Medical Center, Jichi Medical University, Saitama, Japan). All *P*-values less than 0.05 were considered statistically significant.

Results

The demographic data of the patients and the results of the parameters of the S2AIS trajectory are summarized in Table 1, 2, respectively.

Table 3 presents a comparison of the demographic data and parameters of S2AIS insertion in men and women. Men (median, 168.0; interquartile range [IQR], 163.0-172.5 cm) were taller than women (median, 155.3; IQR, 148.3-157.8 cm), and men (median, 64.0; IQR, 54.0-67.2 kg) were heavier than women (median, 52.4; IQR, 43.9-56.0 kg). The lateral angulation for the longest screw was significantly bigger in women (median, 42.0; IQR, 39.4-44.9) than in men (median, 39.7; IQR, 37.6-42.9). The angle range was significantly bigger in women (median, 5.0; IQR, 2.8-7.2) than in men (median, 2.9; IQR, 0-5.9). Men had higher incidence of S2AIS insertion difficulty than women. The other parameters were not significantly different between men and women (Table 3).

Table 4 presents a comparison of the demographic data and parameters of S2AIS insertion between age groups. Patients in their 70 s (median, 154.0; IQR, 147.6-162.3 cm) were significantly shorter than those in the other age groups, and patients in their 60 s (median, 55.8; IQR, 46.5-64.2 kg) and 70 s (median, 53.9; IQR, 49.5-57.6 kg) weighed less than those in their 50 s (median, 63.1; IQR, 52.7-67.3 kg). The longest screw length was significantly shorter in patients in their 50 s (median, 112.5; IQR, 103.2-119.7) than those in their 60 s (median, 121.7; IQR, 111.4-127.3). The other parameters did not significantly differ between age groups (Table 4).

Table 1. Patient Demographic Data.

Number of patients	60
Age (years)	63 (57.0–72.0)
Height (cm)	159.5 (154.3–168.0)
Weight (kg)	56.0 (49.8–64.4)
BMI (kg/m^2)	21.3 (19.8–23.7)

BMI: body mass index

Discussion

The findings of this study validated our hypothesis. In addition, the morphometric features of the pelvis for S2AIS insertion in the Japanese samples were elucidated. In this study, the longest and shortest screw lengths were approximately 110 and 100 mm, respectively. The range of lateral angulation was approximately 40°-50°. These results were fairly similar to those of previous studies[9,13-16]. Matteini et al. recommended that the length of the S2AIS be at least 80 mm[17]. A biomechanical study demonstrated that there was no difference in stiffness between 65- and 80-mm-long screws[18]. Our results indicated that orthopedic surgeons can sufficiently insert S2AIS in Japanese patients.

Most researchers who analyzed caudal angulation defined it as the angle between the vertical line to the frame of the CT scanner and the S2AIS trajectory in the sagittal plane. Sagittal alignments, such as pelvic tilt or sacral slope, differ between populations as well as with age and sex[19-22]; thus, caudal angulation should be measured based on the pelvic mark and not on the frame of the CT scanner to ensure accurate measurement. Interestingly, our caudal angulation was almost parallel to the S1 superior endplate in the sagittal plane. This means that when orthopedic surgeons insert the S2AIS parallel to the S1 superior endplate by using the fluoroscopic outlet view, the screw trajectory is toward the AIIS. In clinical practice, the S2AIS trajectory is directed toward the greater trochanter, but detection of the greater trochanter is sometimes difficult intraoperatively in obese patients. Our results may help us develop a new marker for S2AIS insertion.

S2AIS insertion is associated with several complications, such as damage of the dorsal cortex of the sacrum; inferior damage of the sciatic notch, which could lead to injury of the superior gluteal artery and nerve; and anterior damage of the pelvis, which could lead to injury of several important

Table 2. Parameters of the S2 Alar-iliac Screw Trajectory for All Study Patients (n=120).

Parameter	
Screw length (S) (mm)	103.3 (86.4–110.5)
Screw length (L) (mm)	108.1 (116.4–124.5)
Distance from the EP to the SIJ (S) (mm)	28.2 (26.0–31.3)
Distance from the EP to the SIJ (L) (mm)	31.2 (28.4–35.6)
Lateral angulation (S) (°)	47.3 (43.6–51.8)
Lateral angulation (L) (°)	40.7 (38.4–44.4)
Angle range (°)	4.2 (0–6.9)
Caudal angulation (°)	−2.8 (−6.5–2.7)
Distance from the S2AIS to the acetabular roof (S) (mm)	27.4 (23.9–32.1)
Distance from the S2AIS to the acetabular roof (L) (mm)	23.5 (20.5–27.1)
Distance from the S2AIS to the sciatic notch (S) (mm)	23.1 (19.9–27.1)
Insertion difficulty (number of screws)	32

EP: entry point (of the S2 alar-iliac screw), SIJ: sacroiliac joint, S2AIS: S2 alar-iliac screw, S: shortest, L: longest

Data are presented as median with the first and third quartiles.

Table 3. Comparison of Demographic Data and Parameters of S2AIS Insertion between Sexes.

	Men	Women	P-value
Demographic data			
Number of patients	30	30	
Age (years)	66.5 (54.3–70.0)	62.0 (57.5–73.0)	0.80
Height (cm)	168.0 (163.0–172.5)	155.3 (148.3–157.8)	<0.01*
Weight (kg)	64.0 (54.0–67.2)	52.4 (43.9–56.0)	<0.01*
BMI (kg/m^2)	21.3 (20.3–23.8)	21.9 (18.5–23.5)	0.38
Parameter			
Number of screws	60	60	
Screw length (S) (mm)	102.9 (81.2–114.6)	104.0 (81.2–108.4)	0.42
Screw length (L) (mm)	118.7 (108.2–126.8)	115.4 (108–122.9)	0.19
Distance from the EP to the SIJ (S) (mm)	29.2 (25.5–32.3)	27.8 (26.2–30.9)	0.50
Distance from the EP to the SIJ (L) (mm)	32.3 (29.5–35.7)	30.0 (28.3–33.9)	0.16
Lateral angulation (S) (°)	47.1 (41.9–51.4)	47.9 (45.0–52.2)	0.20
Lateral angulation (L) (°)	39.7 (37.6–42.9)	42.0 (39.4–44.9)	<0.05*
Angle range (°)	2.9 (0–5.9)	5.0 (2.8–7.2)	<0.05*
Caudal angulation (°)	−2.4 (−6.6–1.8)	−2.9 (−6.0–5.1)	0.45
Distance from the S2AIS to the acetabular roof (S) (mm)	26.6 (22.3–32.2)	28.0 (25.1–31.9)	0.23
Distance from the S2AIS to the acetabular roof (L) (mm)	23.7 (20.8–27.3)	22.6 (20.1–27.1)	0.38
Distance from the S2AIS to the sciatic notch (S) (mm)	23.9 (21.2–28.5)	22.3 (19.2–26.6)	<0.05*
Insertion difficulty (number of screws)	22	10	<0.05*

* Data are statistically significantly different (P<0.05).

BMI: body mass index, EP: entry point (of the S2 alar-iliac screw), SIJ: sacroiliac joint, S2AIS: S2 alar-iliac screw, S: shortest, L: longest

Table 4. Comparison of Demographic Data and Parameters of S2AIS Insertion among Age Groups.

	Patient age: 50 s	Patient age: 60 s	Patient age: 70 s	P-value
Demographic data				
Number of patients	20	20	20	
Height (cm)	165.0 (157.2–170.0)	161.5 (156.4–167.8)	154.0 (147.6–162.3)	<0.05*
Weight (kg)	63.1 (52.7–67.3)	55.8 (46.5–64.2)	53.9 (49.5–57.6)	0.11
BMI (kg/m^2)	21.9 (21.1–23.6)	21.3 (19.3–23.3)	20.9 (19.9–23.7)	0.56
Parameter				
Number of screws	40	40	40	
Screw length (S) (mm)	101.5 (84.0–107.3)	103.9 (89.6–111.2)	105.9 (90.4–112.1)	0.41
Screw length (L) (mm)	112.5 (103.2–119.7)	121.7 (111.4–127.3)	118.3 (108.1–124.0)	<0.05*
Distance from the EP to the SIJ (S) (mm)	28.9 (26.0–31.2)	28.4 (25.8–31.1)	27.6 (26.2–31.9)	0.94
Distance from the EP to the SIJ (L) (mm)	31.5 (28.2–35.4)	30.5 (27.4–35.3)	31.0 (29.3–35.6)	0.64
Lateral angulation (S) (°)	47.9 (44.8–52.4)	46.2 (42.6–49.6)	48.7 (43.9–51.9)	0.27
Lateral angulation (L) (°)	42.2 (39.0–46.3)	40.1 (36.8–42.0)	40.5 (38.4–44.0)	0.07
Angle range (°)	3.4 (0–6.6)	4.2 (0–7.1)	4.8 (0.8–6.9)	0.70
Caudal angulation (°)	0.85 (−4.2–4.4)	−2.9 (−6.9–2.2)	−3.7 (−8.7–0.4)	0.13
Distance from the S2AIS to the acetabular roof (S) (mm)	30.2 (24.0–34.1)	27.9 (24.6–31.4)	26.8 (22.4–29.4)	0.15
Distance from the S2AIS to the acetabular roof (L) (mm)	23.5 (21.6–30.0)	22.5 (20.4–26.5)	23.6 (19.5–26.5)	0.26
Distance from the S2AIS to the sciatic notch (S) (mm)	25.7 (22.1–28.1)	22.9 (20.1–27.0)	21.8 (19.2–26.5)	0.15
Insertion difficulty (number of screws)	10	12	10	0.84

* Data are statistically significantly different (P<0.05).

BMI: body mass index, EP: entry point (of the S2 alar-iliac screw), SIJ: sacroiliac joint, S2AIS: S2 alar-iliac screw

vascular, neurological, and visceral structures. Posterior damage of the pelvis usually does not lead to any major complications. To avoid these complications, authors of a previous study recommended that the path of the drill be within 20 mm proximal to the greater sciatic notch and aimed toward the AIIS[23]. In this study, both of the median distances from the S2AIS to the sciatic notch and from the S2AIS to the acetabular roof were more than 20 mm regardless of sex and age. This result indicated that orthopedic surgeons can safely insert the S2AIS in Japanese patients using a trajectory toward the AIIS.

Surprisingly, there were many cases of S2AIS insertion difficulty because we could not achieve a sufficient margin for the posterior cortex of the sacrum. We considered that this was because the posterior cortex of the sacrum was curved in the axial plane. Posterior damage of the sacrum may reduce the screw strength, but no biomechanical study has confirmed this. If the EP of the S2AIS is more medial, such as midpoint between S1 and S2 dorsal foramen[15)], this may decrease the rate of insertion difficulty.

In our study, the lateral angulation was significantly smaller in men than in women. The distance from the S2AIS to the sciatic notch was significantly longer in men than in women. These results were different from those in previous reports[24,25)]. However, the male pelvis is narrow and deep, whereas the female pelvis is wide and shallow; therefore, our results seem more representative of the pelvic features between sexes than those of previous reports[24,25)]. We need to be careful when inserting S2AIS in men because they were found to have higher incidence of S2AIS insertion difficulty than women.

The distance from the S2AIS to the acetabular roof or sciatic notch tended to be shorter in patients in their 70 s than in those of other age groups. Considering the demographic data, which showed that patients in their 70 s were significantly shorter than those in other age groups, a difference in height might have affected the measurement value. Although there was a significant difference in the screw length of the longest S2AIS between age, it is considered that there is no clinical problem because all groups have sufficient screw length.

There were several limitations to the present study. First, our study design was retrospective. Second, the sample size was small. Third, selection bias may have existed because this study included patients who underwent pelvic CT regardless of their disease status.

In conclusion, regarding S2AIS insertion in the Japanese samples, the screw length and lateral angulation were similar to those reported in previous studies. In addition, caudal angulation was almost parallel to the S1 superior endplate in the sagittal plane. S2AIS insertion was difficult in 27% of Japanese patients because of posterior damage to the sacrum. Therefore, it may be necessary to change the EP for S2AIS insertion more medially in Japanese patients.

Conflicts of Interest: The authors declare that there are no relevant conflicts of interest.

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Author Contributions: K.M., H.S., and D.I. contributed to the design of the study, analysis of the results, and writing of the manuscript. H.S. supervised the findings of this work. All authors discussed the results and contributed to the final manuscript.

Ethical Approval: This study was approved by the ethics committee of Nara Medical University (Approval code: 756).

Informed Consent: Informed consent was obtained from all participants in the study.

Device Status/Drug Statement: The manuscript submitted does not contain information about medical device(s)/drug(s).

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