Accuracy of Lateral Mass Screw Insertion during Cervical Spine Surgery without Fluoroscopic Guidance and Comparison of Postoperative Screw Loosening Rate among Unicortical and Bicortical Screws Using Computed Tomography

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Abstract:

Introduction: Pedicle screws (PSs) or lateral mass screws (LMSs) are used in posterior cervical spine fixation. The former are more firmly fixed but are associated with the risk of neurovascular injury and should be inserted using intraoperative imaging or navigation, which may prolong the surgical duration and is not feasible in all hospitals. This prospective clinical study aimed to evaluate the outcomes of LMS insertions without fluoroscopic guidance and screw loosening rates at 6 months postoperatively using computed tomography (CT).

Methods: We examined 38 patients who underwent posterior cervical spine fusion using 206 LMSs in the C3-C6 range between January 2018 and July 2021. The direction of screw insertion followed the Magerl method, and we inserted screws as bicortically as possible without intraoperative imaging. The screw position was examined using CT at 1 week postoperatively. Screw insertion angles, bicortical insertion rate, facet violation, and neurovascular injury were evaluated. Screw loosening with unicortical and bicortical screws (US and BS, respectively) was investigated using CT at 6 months postoperatively.

Results: The average LMS length was 14.1 mm. The average axial and sagittal angles were 33.9° and 29.2°, respectively. Among the 206 LMSs inserted, 167 were BS; of these, 94.6% had screw length protrusion of 0-2 mm. Facet violation was observed in 3.4% of all screws but without neurovascular injury. Six months postoperatively, loosening of 25 screws (12.1%) occurred, including 17 (18.3%) USs and 8 (8.39%) BSs. The screw loosening rate was significantly higher in US than for BS (43.6% [17/39] vs. 4.8% [8/167], P<0.01).

Conclusions: Over 80% of LMSs were inserted bicortically without intraoperative imaging. By devising the screw length selection process, we inserted for screw loosening was more common in US and more likely at the fixed end.

Keywords:

Cervical spine, Lateral mass screw, Fluoroscopy, Bicortical screw, Screw loosening

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Introduction

Posterior cervical spine fusion surgery has become a common surgical procedure following recent technological developments, with pedicle screws (PSs) or lateral mass screws (LMSs) often being used during posterior cervical spine fixation surgery[1]. Although PSs can be more firmly fixed than LMSs, they are associated with the risk of neurovascular injury. In addition, the pedicle diameter is small in the middle and lower cervical vertebrae, and insertion difficulties are noted in some cases[2,3]; therefore, the use of intraoperative imaging and navigation to guide PS insertion is desirable[4].

The implementation of intraoperative fluoroscopy is not feasible in all hospitals, and the use of surgical navigation aids extends the surgical duration and is either expensive or not available in some hospitals. In our institution, LMSs are used without any intraoperative imaging guidance in patients

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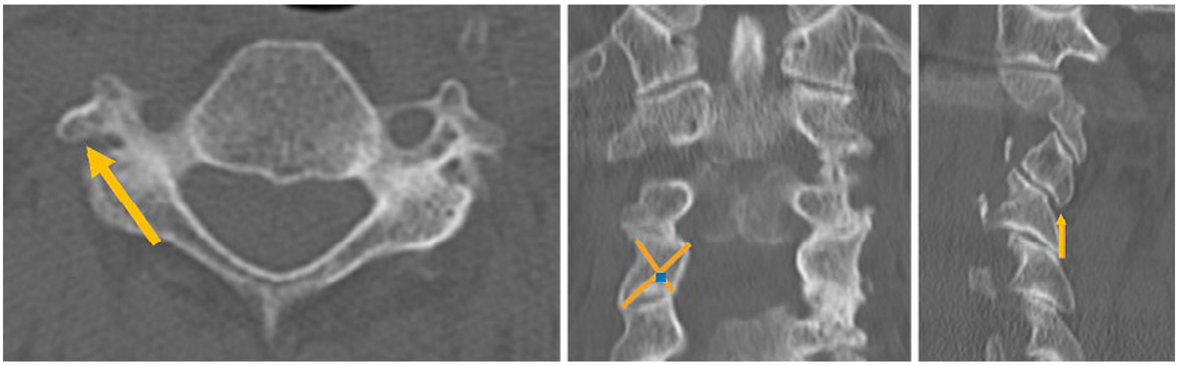

Figure 1. Insertion point and direction confirmation using preoperative computed tomography.
Left (axial): screw direction.
Center (coronal): screw insertion point.
Right (sagittal): measurement of penetration distance from the caudal side.

with cervical spine instability. LMSs are known to be inferior to PSs in terms of their fixation force; however, they have a lower risk of vascular injury with respect to the puncture direction. Moreover, they can be used for cases with a small pedicle diameter, which hinders the bone insertion of PSs. While there have been previous reports on bicortical LMS insertion without imaging guidance, to the best of our knowledge, there are no reports on the accuracy of LMS insertion using computed tomography (CT). Heller et al. reported that the pullout strength of LMSs is stronger than that of unicortical screws (US) when inserted into bicortical screws (BS)[5]; hence, we try to insert LMSs bicortically as much as possible.

Therefore, this study aimed to examine the accuracy of our LMS insertion and determine the difference in the incidence of screw loosening between BS and US at 6 months postoperatively using CT.

Materials and Methods

In this prospective clinical study, we examined 206 LMSs used for C3-C6 fixation in 38 consecutive patients with motor-skill dysfunction who underwent cervical laminoplasty and fusion surgery using LMSs between January 2018 and July 2021. The patients provided informed consent prior to study participation. Individuals included in the study comprised those with cervical spondylotic myelopathy with local kyphosis that resolved upon extension, cervical spondylotic myelopathy with herniated disk, ossification of the posterior longitudinal ligament (OPLL), cervical spondylolisthesis, and metastatic cervical spine tumor.

Technique

Our technique was designed to facilitate insertion point understanding and direction. The insertion point was initially determined using preoperative CT. As the lateral mass (LM) was quadrangular, we marked the intersection of its diagonals. We created an insertion point 1 mm medial and 1 mm caudal to the marked intersection. Then, we confirmed the insertion point using axial and sagittal CT images; the positional relationship with the inflection point of the vertebral lamina was also determined simultaneously. Using a sagittal CT image, we measured (in mm) the distance of the insertion point cranially and the distance from the caudal end of the LM. The intervertebral joint's cranial side was located in the deep layer, while the caudal side was exposed in the shallow layer. Intraoperatively, it was difficult to grasp exactly how far the cranial end was because the cranial side is deep; accordingly, measurements from the caudal side were taken for enhanced accuracy (Fig. 1). Furthermore, we recommend that screw length measurement be based on CT because the actual puncture direction may differ from that observed on preoperative X-ray images; therefore, the exact length cannot be measured using this method.

The cervical spine's position was preoperatively examined using X-ray imaging and the headrest was firmly fixed on the operating table using tapes. It is important to preoperatively confirm that the cervical spine is not rotated.

After establishing the insertion point, a bone hole was created using a 3-mm course round diamond burr (Primado 2, Nakanishi Inc., Kanuma, Japan) aimed toward the LM diagonal; the index was used as the diagonal line when determining the insertion point. This diagonal line could be easily visualized by marking the LM with an electric knife. The axial angle of screw insertion was similar to that used in the Magerl method[6]. It is based on the vertebral lamina's inclination. As the drill device must be tilted beyond the midline of the lower vertebral body's spinous process, the device will interfere with any remaining spinous processes, resulting in a shallower penetration angle and increased risk of vascular injury. Therefore, it is important to separate the spinous processes.

Once the insertion position and angle were determined, drilling was performed using a drill that sequentially increases in 2-mm increments from 10 mm. A sounder was used to assess whether the cortex had been penetrated on the contralateral side. If the cortex was intact on the contralateral side, it was gently pushed with the sounder to con-

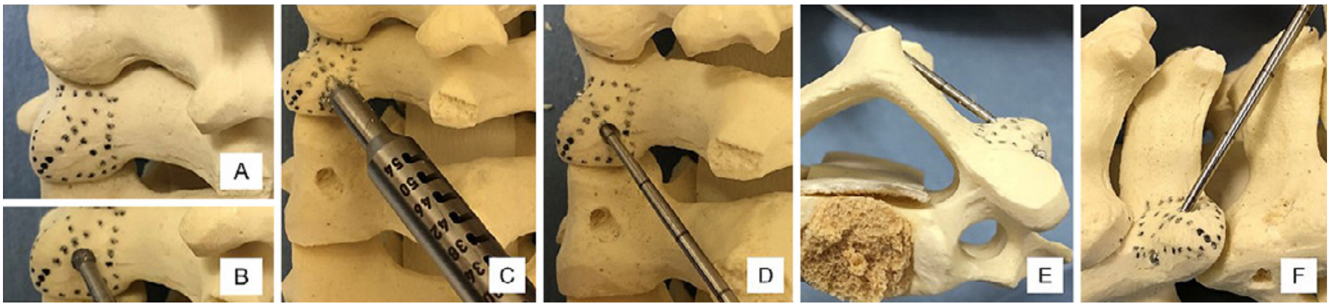

Figure 2. Insertion point determination of the bone hole and insertion direction using a bone model.
A. Mark the lateral mass and draw a diagonal to confirm the intersection.
B. Create a bone hole using a 3-mm ball air drill. Create a bone hole by shifting the ball halfway to the medial and caudal sides.
C. Create a bone hole using a 3-mm ball air drill. Drilling is performed along the diagonal line drawn toward the lateral mass on the outer cranial side. The spinous process should be removed, as the drill needs to be tilted beyond the midline spinous process of the next lower vertebral lamina.
D. Coronal direction is diagonal to the lateral mass.
E. Axial direction follows the vertebral lamina inclination.
F. Sagittal side is parallel to the facet joint.

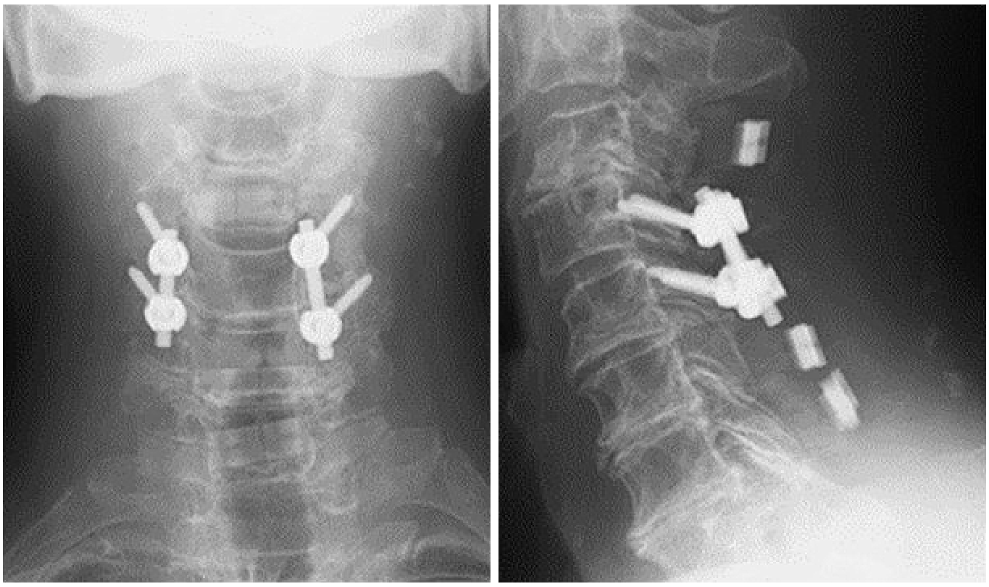

Figure 3. Postoperative X-ray imaging. The optimal position and length on anteroposterior (left) and lateral (right) images are shown.

firm whether the cortex protruded on the contralateral side. If the cortex was thin, even a blunt sounder could pierce the cortex on the contralateral side. If the cortex on the contralateral side was not perforated, the drill size was increased, and the same procedure is performed. The sounder was drilled and checked until the cortex had been penetrated (Fig. 2).

The most important part of our technique is as follows: To determine the screw length, a screw that is one size smaller than that inserted after penetrating the cortex on the opposite side was used; for example, if drilling was performed for up to 16 mm and the cortex was observed to be penetrated after checking with a sounder, a 14-mm screw was inserted. Subsequently, tapping was performed at the same diameter as the screw. After reconfirming the screw hole with the sounder, the screw was inserted; screws are 3.5 mm in diameter. No imaging was performed during these procedures. It is possible to have flexibility across individual patients because the index of this procedure is determined by the vertebral lamina shape and LM (Fig. 3).

The evaluation items included the screw insertion angle (axial and sagittal angles), whether the screw could be inserted into a bicortical system, the presence or absence of vertebral artery (VA) injury, nerve root injury, or facet violation. All items were assessed using CT at 1 week postoperatively. In addition, screw loosening with US and BS was investigated using CT at 6 months postoperatively. The presence of loosening signs was considered positive.

Table 1. Type and Number of Screws at Each Vertebral Body Level.

	C3		C4		C5		C6		Total
	R	L	R	L	R	L	R	L	
All screws	20	20	35	35	35	35	13	13	206
Bicortical screws	16	18	26	24	28	29	13	13	167
Unicortical screws	4	2	9	11	7	6	0	0	39

R, right; L, left

Table 2. Unicortical and Bicortical Screw Accuracy.

Screws	Unicortical screws	Bicortical screws (0-2 mm)	Bicortical screws (>2 mm)
Number	39	158	9

Table 3. Loosening Rate among the Unicortical Screws (US) and Bicortical Screws (BS) Groups.

	Loose screws (n)	Loosening rate (%)	P-value
US group	17	43.6 (17/39)	<0.01
BS group	8	4.8 (8/167)	
All screws	25	12.1 (25/206)	

Statistical analysis

Data were statistically compared using Pearson's chi-square test for the loosening rate between the BS and US groups. Considering the screw loosening rate, the chi-square test and one-way ANOVA were used to evaluate sex and number of intervertebral fusions, respectively. All statistical analyses were performed using IBM SPSS software version 24.0 (IBM Corp., Armonk, NY, USA), and a P-value of <0.05 indicated statistical significance.

Results

Among the 38 patients (25 male and 13 female patients) enrolled, 17 had cervical spondylotic myelopathy and kyphosis, 2 had cervical spondylotic myelopathy and herniated disk, 15 had cervical OPLL, 3 had cervical spondylolisthesis, and 1 had metastatic spinal tumor. The number of LMSs examined was 206; the screws inserted into each LM are shown in Table 1. The fusion level in 3, 13, 3, 9, 2, and 8 cases was at the C3-4, C4-5, C5-6, C3-5, C4-6, and C3-6 intervertebral levels, respectively. The screw's average axial and sagittal insertion angles were 33.9° (21.3°-47.1°) and 29.2° (−9.0° to 47.4°), respectively.

Regarding whether the screw could be bicortically inserted, if it was pulled out contralaterally in at least one direction in the axial, sagittal, or coronal slices on postoperative CT, it was considered BS. BS comprised 81.1% (167/206) of the LMSs, and the average screw length was 14.1 (10-20) mm. The screw length was evaluated on a three-point scale with reference to Neo et al.'s classification[7]. We evaluated US, BS with a contralateral screw protrusion of 0-2 mm (BSa), and BS with a contralateral screw protrusion of ≥2 mm (BSb). There were 39 US, 158 BSa, and 9 BSb. With BSa considered the optimal screw length, 94.6% of the BS were of the optimal length; no BSb protruded >4 mm (Table 2). Neurovascular injuries were not observed in any patient, whereas facet violation was identified in 3.4% of all the screws. No LM excisions were required during surgery.

At 6 months postoperatively, 25 of all screws had loosened (12.1%). Of these, 17 screws (68%; 17/25) were loosened at the fixed end. US loosening was observed in 17 screws and BS loosening in 8. The screw loosening rates among US and BS were 43.6% (17/39) and 4.8% (8/167), respectively, with the US group showing a significantly higher rate (P<0.01) (Table 3). Moreover, we examined the association of sex and the number of intervertebral fusions with screw loosening. Screw loosening was observed in 11 men and 5 women, with no significant difference between the sex. It was also observed in 7, 8, and 1 cases with 2, 3, and 4 intervertebral fusions, respectively. One-way ANOVA revealed no significant differences among the three groups.

Discussion

In this study, we performed LMS insertion without intraoperative imaging guidance during posterior cervical fusion surgery. This study described the method followed and examined the screw placement accuracy. In addition, we evaluated LMS loosening at 6 months postoperatively using CT.

At 14.1 mm, our average screw length was longer than that reported in previous studies. Previous studies reported average lengths of 14.05[6], 13.47[8], and 12.8 mm[9]. Regarding the insertion angle, we demonstrated average axial and sagittal angles of 33.9° (21.3°-47.1°) and 29.2° (−9.0°-47.4°), respectively; previous studies reported axial and sagittal angles of 25° and 20°-30°[6], 10° and 30°-40°[8], and 30° and 15°, respectively[9]. Thus, our method resulted in larger penetration angles than those previously reported.

As the insertion point was on the medial and caudal sides and the screw insertion angle was larger than that previously reported, the screw length, as determined by capturing the longer diagonal line of the LM, was longer than that previously reported as well[6,8,9]. A larger insertion angle implies that the screw points toward the cranial side and outside of

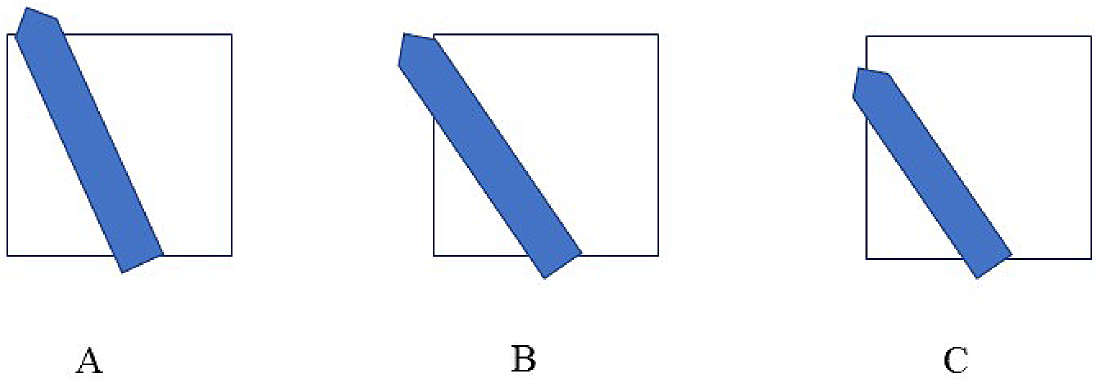

Figure 4. Puncturing the lateral mass screw's contralateral cortex and the relationship between the length and angle. (A, B) Even with the same insertion point and screw length, an increased insertion angle will result in a diagonal insertion; thus, the tip will protrude. (B) There are long and short protrusions at the screw's tip because the screw is diagonally inserted. (B, C) If same-length screws, similar to those used for penetration of the contralateral cortex, are inserted, they will protrude from the opposite side. Protrusion can be prevented by inserting a screw that is one size smaller, and a part of it can also be inserted as a bicortical screw.

the LM. Therefore, we believe that this may reduce the incidence of VA injury. Previous studies have also emphasized the importance of swinging the angle in the vertical and horizontal directions as much as possible to avoid neurovascular injury[10,11]. Contrastingly, if the angle is too large, the risk of LM excision during surgery is increased. Nevertheless, in this study, the LM was not subjected to any damage intraoperatively.

Regarding screw length, as the average vertical distance between the LM center and intervertebral foramen from C3 to C6 is approximately 9-12 mm, Sekhon suggests inserting the 14-mm LMS at a particular angle to ensure safe screw insertion into the bicortical area[12]. Herein, the average screw length was 14.1 mm, and the outcomes after its use were similar to those noted in Sekhon's study. We assessed screw length using CT but could not find any other study that assessed the length and accuracy of BS using CT base; hence, we used the classification of Neo et al.[7] to assess screw length using CT base. BS accounted for 81.1% of all screws. Sekhon also reported that the proportion of successful bicortical insertion of screws was 93.6%[12]; however, the study did not state whether the screws were inserted under intraoperative imaging guidance. Moreover, Sekhon reported that some BS had violated facets or breached the transverse foramina. Furthermore, the proportion of BS with optimal screw length was not evaluated.

Based on the above, we investigated the accuracy of BS with CT. Among the BS, the optimal screw length was observed in 94.6% (158/167) of LMSs, which was highly accurate. This could be achieved by inserting a screw that is one size smaller in terms of length once the contralateral cortex is penetrated and by setting a firm angle during screw insertion. If the insertion angle is large when using the same-length screw after cortical penetration, part of the screw tip will extrude to the contralateral cortical side; similarly, if the screw length is the same as that when the contralateral bone was penetrated, part of the tip will inevitably extrude. Therefore, inserting a screw that is one size smaller allowed for highly accurate insertion of the optimal screw length while maintaining the bicortical position (Fig. 4). If the screw head floats, it becomes US; therefore, it is important to ensure complete and firm screw insertion. Furthermore, even with bicortical penetration of the screw, the risk of nerve injury is increased if the screw is too long[13]; as such, it is important to insert a screw of optimal length. Ebraheim et al. also reported that while intraoperative lateral imaging is not useful for screw length determination, it can help reduce the risk of neurovascular injury[14]. We also do not use intraoperative fluoroscopy to determine the screw length because we believe that probe confirmation is effective for screw length determination. Moreover, we believe that our technique is useful because it can achieve high accuracy, even without intraoperative imaging guidance.

We also examined the bicortical penetration of the screw. Heller et al. reported that the pullout strength of LMSs was stronger than that of US when penetrated bicortically, adding that it was better to insert the screw bicortically as often as possible[5]. They also reported that the insertion direction used in the Magerl method was stronger than that used in the Roy-Camille method. Our insertion method was more angled than the Magerl method, and no screws were pulled out.

At 6 months postoperatively, the number of loosened screws was 25 (12.1%; loosening rate, 43.6% in US and 4.8% for BS). No screws were pulled out in this study. Loose screws destroy the LM and may cause neurovascular injuries and result in the screws being pulled out. In this study, screw loosening at the fixed end was common (68%). Since the force applied to the instrument is higher at the fixed end, it is better to be aware of bicortical insertion to avoid implant failure. These results suggest that it is important to insert screws as bicortically as possible; particularly, insertion to the fixed end should be given careful attention. Simon et al. reported that LMS insertion without intraoperative imaging guidance reduced the amount of radiation exposure and surgical duration[15]. They noted that if the established guidelines for screw positioning and insertion are carefully adhered to with a complete understanding of the LM anatomy, the procedure is safe and effective; therefore, it should be performed by skilled surgeons who are familiar with the procedure and anatomy. We agree with this point and believe that it is important to have a sufficient understanding of the LM anatomy in preoperative planning and physical grasping of the LM intraoperatively. In minimally invasive spine surgery, the radiation dose to the fingers was 0.15-0.76 mSv[16,17]. The radiation exposure dose to the hand in general orthopedic surgery is estimated to be 0.08-0.2 mSv[18], and the exposure in spine surgery is an issue to be considered. According to Simon et al., the omission of intraoperative fluoroscopy significantly reduces the risk of hand and hand radiation exposure in spine surgery and patient and operator exposure to harmful radiation and should also shorten the time of operation[15]. Although we did not measure actual radiation exposure doses in this study, our procedure should also reduce radiation exposure because it does not use intraoperative fluoroscopy.

This study has some limitations. First, only a small number of patients and screws were assessed. Second, postoperative clinical results were not evaluated. Further research on the topic, such as clinical evaluation using the Japanese Orthopedic Association score and Visual Analog Scale, and examination of the bone union rate, is warranted. However, there were no cases of reoperation and no axial pain that made patients' daily lives difficult. Finally, factors such as bone density should also be considered; however, there are no data on these factors in this study. Therefore, we believe that these data should be collected in the future.

In conclusion, BS can be inserted with high accuracy without intraoperative imaging guidance, and a high optimal screw length ratio is achievable. In this study, the screw loosening rate was high in US and at the fixed end; however, there were no complications due to screw loosening. Therefore, it is recommended that screws be inserted as bicortically as possible.

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

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Author Contributions: H.M. and Y.U. were involved in the conceptualization and design of the study, as well as in data acquisition. H.S. and Y.T. supervised the writing of the manuscript and were involved in its critical revision. All authors have discussed the results and have contributed to the final manuscript.

Ethical Approval: This study was approved by the Ethics Committee of Kashiba Asahigaoka Hospital (Approval code: 08-1-014)

Informed Consent: The patients provided informed consent prior to study participation.

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