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1 **Subaxial sagittal alignment after atlantoaxial fixation techniques**

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9 materials or methods used in this study or the findings specified in this paper.

10

11 **Running head:** Subaxial sagittal alignment

12

13 **Keywords:** C1 lateral mass screw; Magerl procedure; C1–C2 fixation angle; subaxial sagittal
14 alignment

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1 **Abstract**

2 **Study Design:** Retrospective clinical case series.

3 **Objectives:** To evaluate the association between C1–C2 fixation angle and postoperative
4 C2–C7 alignment in the sagittal plane after C1 lateral mass screw with C2 pedicle screw fixation
5 (C1-LMS) or Magerl with wiring technique.

6 **Summary of Background Data:** Various techniques for posterior correction and fusion, such as
7 the Magerl procedure with posterior wiring and C1-LMS procedures, are used for treating
8 atlantoaxial instability. However, only few studies investigating the relationship between
9 postoperative C1–C2 angle and C2–C7 sagittal alignment change after C1–C2 fixation have been
10 reported.

11 **Methods:** We retrospectively followed-up 42 patients who underwent the C1-LMS (22 patients)
12 or Magerl with wiring procedure (20 patients) to treat C1–C2 instability for >2 years. The
13 atlantodental interval (ADI), space available for the spinal cord (SAC), and O–C1, C1–C2,
14 C2–C3, and C2–C7 angles were measured.

15 **Results:** Significant reduction in ADI and increase in SAC were observed in both groups.
16 Although the preoperative C1–C2 angles were similar, the angle at the final follow-up was
17 higher in the Magerl with wiring group than in the C1-LMS group ($P < 0.01$). The C1–C2
18 fixation and postoperative C2–C7 angles were negatively correlated in both groups (C1-LMS

1 group, $r = -0.55$, $P < 0.01$; Magerl with wiring, $r = -0.62$, $P < 0.01$).

2 **Conclusions:** Increased lordotic change in the C1–C2 angle was associated with increased
3 kyphotic changes in the C2–C7 angle after both procedures. The C1-LMS procedure effectively
4 controlled C1–C2 sagittal alignment during surgery. To decrease the risk of postoperative
5 subaxial kyphotic changes, the C1–C2 fixation angle should be carefully determined.

6

7 **Introduction**

8 Various techniques for posterior correction and fusion have been used to treat atlantoaxial
9 instability. The transarticular C1–C2 fixation technique, introduced by Magerl and Seemann,¹ is
10 typically used because it provides rigid fixation immediately after surgery and has higher fusion
11 rates than conventional wiring techniques.^{2–4} However, transarticular screw fixation is reported to
12 be technically demanding and carries the risk of vertebral artery injury.^{5,6} In addition, the Magerl
13 technique has to be combined with posterior wiring techniques (Magerl with wiring) to
14 maximize stability.⁷ Recently, another C1–C2 posterior fixation technique using a C1 lateral
15 mass screw with C2 pedicle screw fixation (C1-LMS) was introduced by Goel and Laheri⁸ and
16 modified by Harms and Melcher.⁹ In the C1-LMS technique, individual placement of screws in
17 C1 and C2 allows direct manipulation of C1 and C2, simplifying the subsequent reduction
18 maneuver and fixation during surgery.^{8–11} In addition, superior and medial placement of the C2

1 screw involves less risk to the vertebral artery.⁹

2 Although the clinical results of different surgical procedures for atlantoaxial instability
3 are satisfactory in decreasing neck pain and neurological symptoms^{1,12}, some patients show
4 decreases in subaxial cervical lordosis after surgery. However, few studies investigating the
5 relationship between postoperative C1–C2 angle and C2–C7 sagittal alignment change after
6 C1–C2 fixation have been reported.¹³⁻¹⁶ To lessen the risk of postoperative malalignment at the
7 subaxial cervical spine, greatest care must be taken to determine the C1–C2 fixation angle during
8 surgery.¹⁶ To the best of our knowledge, no study has compared the radiological results of
9 postoperative subaxial alignment after C1-LMS and Magerl procedures. This study aimed to
10 evaluate the association between C1–C2 fixation angle and postoperative C2–C7 alignment in
11 the sagittal plane after the C1-LMS or Magerl with wiring procedure.

12

13 **Materials and Methods**

14 *Patient demographics*

15 After obtaining the approval of the institutional review board, 46 patients who underwent the
16 C1-LMS procedure or Magerl with wiring procedure by a single surgeon for atlantoaxial
17 instability were retrospectively analyzed from 1992 to 2010. The minimum follow-up period was
18 2 years after surgery. We initially used the Magerl with wiring procedure exclusively between

1 1992 and 2002. Between 2003 and 2010, we primarily used the C1-LMS procedure. However,
2 when we decided that screw insertion into the C1 lateral mass or C2 pedicle was difficult
3 because of the narrow lateral mass or pedicle, we performed the Magerl with wiring procedure.

4 Twenty-four patients underwent the C1-LMS procedure between 2003 and 2008. Two
5 cases were excluded from this study, and the remaining 22 patients [average age, 59.6 years
6 (range, 15–81); men, 4; women, 18; mean follow-up period, 41.1 months (range, 24–96)] were
7 included in this study and placed in the C1-LMS group. One of the excluded cases involved a
8 female patient with os odontoideum whose posterior arch was fractured 1 month after initial
9 surgery and who required O–C2 posterior fusion as a salvage surgery. Another case involved a
10 male with os odontoideum in whom bony union could not be achieved and underwent O–C2
11 posterior fusion 6 months after the initial surgery. The causes of C1–C2 subluxation were
12 rheumatoid arthritis (RA) ($n = 14$), os odontoideum ($n = 2$), trauma ($n = 4$), and others ($n = 2$).

13 Between 1992 and 2008, 22 patients underwent the Magerl procedure combined with
14 Gallie³ or Brooks–Jenkins² wiring technique by the same surgeon. Of these, two female patients
15 with RA who underwent concomitant subaxial laminoplasty were excluded, and the remaining
16 20 patients [men, 8; women, 12; average age at surgery, 45.5 years (range, 12–71 years); mean
17 follow-up period was 88.6 months (range, 24–180)] were evaluated as the Magerl with wiring
18 group. The causes of C1–C2 subluxation were RA ($n = 13$), os odontoideum ($n = 4$), and trauma

1 (n = 3).

2

3 *Surgical techniques*

4 *C1-LMS procedure*

5 Before surgery, a Mayfield three-point head holder was used to attempt reduction of C1–C2
6 subluxation. A C1 lateral mass screw was inserted via the C1 posterior arch under lateral
7 fluoroscopic guidance.¹⁷ After insertion of C2 pedicle screws, contoured plates were placed to
8 connect the C1 lateral mass and C2 pedicle screws to reduce subluxation and then fixed under
9 fluoroscopy.⁸⁻¹¹ When C1–C2 reduction was insufficient during surgery, washers were placed on
10 the C2 pedicle screw heads to reduce C1–C2 translation. Finally, an iliac bone was grafted.

11

12 *Magerl with wiring procedure*

13 In the same manner as used in the C1-LMS procedure, a Mayfield head holder was used to
14 attempt reduction of C1–C2 subluxation before surgery. Cannulated screws were placed for
15 bilateral transarticular fixation under lateral fluoroscopic guidance.^{1, 18} After screw placement,
16 the Gallie³ or Brooks–Jenkins² wiring method was used to fix an iliac bone graft.

17 A postoperative Philadelphia collar was applied in patients who underwent both
18 procedures for 6–12 weeks to enhance fusion.

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Radiological evaluations

The atlantodental interval (ADI) in the flexion position was evaluated before surgery, immediately after surgery, and at the final follow-up. Space available for the spinal cord (SAC) was also measured on lateral radiographs in the neutral position.¹⁸ Sagittal angles of O–C1, C1–C2, C2–C3, and C2–C7 were measured on lateral X-rays in the neutral position. The O–C1 angle was measured between McRae’s line and the line passing through the center of the C1 anterior arch and the center of the C1 posterior arch (Fig. 1a).¹⁶ The C1–C2 angle was measured between the line passing through the center of the C1 anterior arch and the center of the C1 posterior arch and the inferior line of the C2 vertebra (Fig. 1a).¹⁶ The C2–C3 and C2–C7 angles were obtained from the angle between the posterior vertebral tangent of C2–C3 and C2–C7, respectively (Fig. 1b).

Statistical analyses

The data are expressed as means and standard deviations. Paired t-tests or Pearson’s correlation coefficient methods were used to perform statistical analyses. Differences with P values of <0.05 were considered statistically significant.

1 **Results**

2 *Patient Demographics*

3 There was a statistical difference in the average surgical duration between the C1-LMS (89.3 ±
4 21.0 min) and Magerl with wiring groups (119.8 ± 39.7 min; P = 0.002). The average
5 intraoperative blood loss was 66.7 ± 93.8 ml and 77.3 ± 63.3 ml in the C1-LMS and Magerl with
6 wiring groups, respectively (P = 0.50). Bony union was achieved in all cases in this population.
7 There was no case of deep infection that required metal removal in either group. In addition,
8 there were no neurological complications related to screw insertion in both groups. There was no
9 VA injury in the C1-LMS group. Although one VA injury was seen in the Magerl with wiring
10 group while tapping a screw hole; bleeding was controlled by packing bone wax, and no clinical
11 symptom was observed after surgery. No patient required additional surgery until the final
12 follow-up.

13

14 *Radiological parameters*

15 *ADI and SAC*

16 Both the C1-LMS and Magerl with wiring groups showed significant reductions in ADI (Table 1).
17 In the C1-LMS group, the average preoperative ADI was 8.5 mm, which decreased to 1.6 mm
18 after surgery (P < 0.0001). In the Magerl with wiring group, the average preoperative ADI was

1 8.1 mm, which decreased to 2.5 mm after surgery ($P < 0.0001$). These reductions were
2 maintained at the final follow-up, and no statistical differences were observed between the
3 postoperative and final follow-up measurements in either group ($P = 1.0$). The change in SAC
4 was similar in both groups (Table 1). In the C1-LMS group, the average preoperative SAC was
5 12.2 mm, which improved to 19.1 mm after surgery. In the Magerl with wiring group, the
6 average preoperative SAC was 13.9 mm, which improved to 19.4 mm after surgery ($P < 0.0001$).
7 Those reductions were maintained at the final follow-up, and no statistical differences were
8 observed between postoperative and final follow-up measurements in either group ($P = 1.0$).
9 These results indicated that both surgical procedures were equally successful in reducing C1–C2
10 translation.

11

12 *C1-C2 angle*

13 In the C1-LMS group, the average C1–C2 angle before surgery was 19.1° , which remained
14 significantly unchanged at 19.0° after surgery ($P = 0.48$). At final follow-up, the average C1–C2
15 angle was 18.5° , but this angle was not significantly different relative to the postoperative
16 measurement ($P = 0.19$). Conversely, in the Magerl with wiring group, the average C1–C2 angle
17 of 23.4° before surgery significantly increased to 28.3° after surgery ($P = 0.02$), which remained
18 essentially unchanged at 28.5° at the final follow-up.

1

2 *O–C1 and C2–C3 angle*

3 There was no significant change between the pre- and postoperative O–C1 angle in either group.

4 Similarly, no significant difference was observed in the C2–C3 angle change in either group

5 (Table 2).

6

7 *C2–C7 angle*

8 The average C2–C7 angle only showed a slight increase from 19.6° to 21.9° in the C1-LMS

9 group and 8.9° to 10.5° in the Magerl with wiring group after surgery. Although significant

10 differences were observed, this angle decreased at final follow-up relative to the preoperative

11 angles in both groups (Table 2).

12

13 *Association between the C1–C2 angle at the final follow-up and the postoperative C2–C7 angle*

14 *change*

15 We further analyzed the association between the C1–2 and C2–7 angle. There was no statistically

16 significant correlation between the C1–C2 angle at the final follow-up and C2–C7 angle change

17 (angle at final follow-up–preoperative angle) in either the C1-LMS group ($r = -0.05$, $P = 0.84$)

18 (Fig. 2a) or Magerl with wiring group ($r = -0.13$, $P = 0.59$) (Fig. 2b). These results suggest that

1 the magnitude of postoperative reduction in the C2–C7 angle did not depend on the absolute
2 value of the postoperative C1–C2 angle in either procedure.

3

4 *Association between the C1–C2 and C2–C7 angle change*

5 There was a negative linear correlation between the C1–C2 angle change (angle at final
6 follow-up–preoperative angle) and the C2–C7 angle change in the C1-LMS group ($r = -0.55$, $P <$
7 0.01) (Fig. 3a) and Magerl with wiring group ($r = -0.62$, $P < 0.01$) (Fig. 3b). These results
8 indicate that increased lordotic change in the C1–C2 angle after surgery was associated with
9 increased kyphotic change in the C2–C7 angle in both procedures (Fig. 4).

10

11 **Discussion**

12 Many reports on C1–C2 posterior fusion procedures have described surgical techniques,
13 improvement in clinical symptoms, and perioperative complications.^{4, 6, 19, 20} However, only a
14 few studies have focused on the association between C1–C2 fixation angle and postoperative
15 subaxial sagittal alignment change.¹³⁻¹⁶ Yoshimoto et al.¹⁶ documented that there was a linear
16 correlation between an increase in C1–C2 lordosis and a decrease in C2–C7 lordosis after C1–C2
17 arthrodesis by wiring alone, the Magerl procedure combined with wiring, or the Halifax clamp
18 procedure. They concluded that in any type of surgery, C1–C2 fixation in the hyperlordotic

1 position would lead to postoperative subaxial kyphosis. Ishii et al.¹³ documented that excessive
2 correction of the C1–C2 angle is likely to cause cervical lordosis and development of
3 postoperative subaxial subluxations in rheumatoid arthritis. In the current study, we first
4 compared the postoperative C2–C7 sagittal angle change between the C1-LMS and Magerl with
5 wiring procedures. Our results were consistent with those of previous reports describing a
6 negative linear correlation between the perioperative change in the C1–C2 and C2–C7 sagittal
7 angles.

8 In this study, significant corrections in postoperative ADI and SAC were observed in
9 both groups. However, the average postoperative C1–C2 sagittal angles were more lordotic in the
10 Magerl with wiring group than in the C1-LMS group. These results suggest that both the
11 C1-LMS and Magerl with wiring procedures provide acceptable reduction of C1–C2 translation,
12 whereas it is easier to control the C1–C2 fixation angle in the C1-LMS procedure than in the
13 Magerl and wiring technique. Indeed, both techniques may fix the C1–C2 joint in the surgeon’s
14 desired position. However, in the Magerl technique, the fixation angle strongly depends on the
15 preoperative neck position,¹⁶ whereas the C1-LMS procedure is effective in controlling C1–C2
16 sagittal alignment during surgery. In addition, because the posterior wiring techniques used to
17 supplement the Magerl procedure depend primarily on the compression force between grafted
18 bone and the C1–C2 laminae, this procedure has a tendency to fix the C1–C2 joint in the

1 hyperlordotic position.¹³ Matsumoto et al.²¹ recommended the application of structural
2 interlaminar spacers, such as ceramic spacers or titanium mesh cages, instead of autologous bone
3 that can maintain proper cervical alignment for posterior atlantoaxial transarticular screw
4 fixation.

5 In this study, the O–C1 angle was not significantly decreased after surgery even in the
6 Magerl with wiring group, while there were statistically significant negative correlations between
7 the C1–2 and C2–7 angle changes in both the C1-LMS and Magerl with wiring groups. These
8 results suggest that the increased C1–2 lordotic alignment was not readily compensated by the
9 occipital–C1 joint, but was mostly compensated by the subaxial alignment. To decrease the risk
10 of postoperative subaxial kyphotic change, surgeons should take great care in determining the
11 C1–C2 fixation angle. Nojiri et al.²² stated that the mean C1–C2 angle in healthy individuals was
12 $26.5^\circ \pm 7^\circ$ in men and $28.9^\circ \pm 6.7^\circ$ in women. In addition, several investigators have noted that
13 the optimum C1–C2 angle for C1–C2 fixation should be approximately 20° .^{23, 24} Although an
14 ideal C1–C2 fixation angle remains unknown in this study, an increase in the C1–C2 sagittal
15 angle would be a risk factor for postoperative subaxial kyphotic change.

16 The limitations of this study were (1) the difference in the follow-up periods between
17 the two groups, (2) heterogeneous background of diseases, and (3) lack of clinical symptoms
18 evaluation. Further investigations are required with longer follow-up periods to evaluate the

1 relationship between these radiological changes and clinical outcomes.

2

3 **Conclusions**

4 The results indicate that increasing lordotic change in the C1–C2 angle after surgery is associated
5 with kyphotic change in the C2–C7 angle for both procedures. The C1-LMS procedure was
6 effective in controlling C1–C2 sagittal alignment during surgery. To decrease the risk of
7 postoperative subaxial kyphotic change, surgeons should take great care in determining the
8 C1–C2 fixation angle.

9

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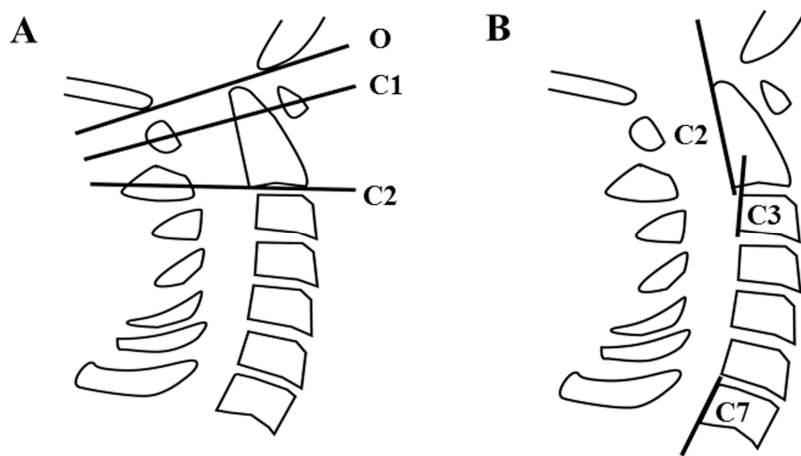
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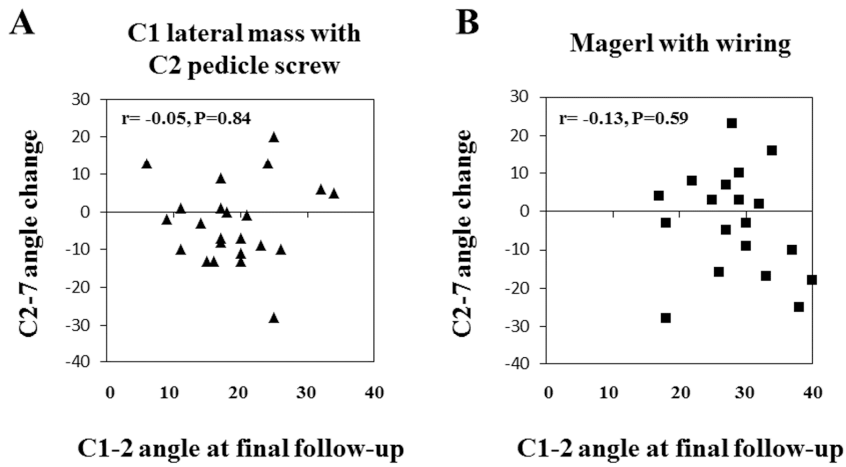
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12

13 **Figure legends**



1
 2 **Fig 1** Schematic drawings of radiological parameters. **A:** The O–C1 angle was measured
 3 between the McRae’s line and the line passing through the center of the C1 anterior arch and the
 4 center of the C1 posterior arch. The C1–C2 angle was measured between the line passing
 5 through the centers of the C1 anterior and posterior arches and the line tangential to the inferior
 6 border of the C2 body. **B:** The C2–C3 and C2–C7 angles were measured between the posterior
 7 tangent of the C2, C3, and C7 body. Lordosis was expressed as a positive value and kyphosis as
 8 a negative value

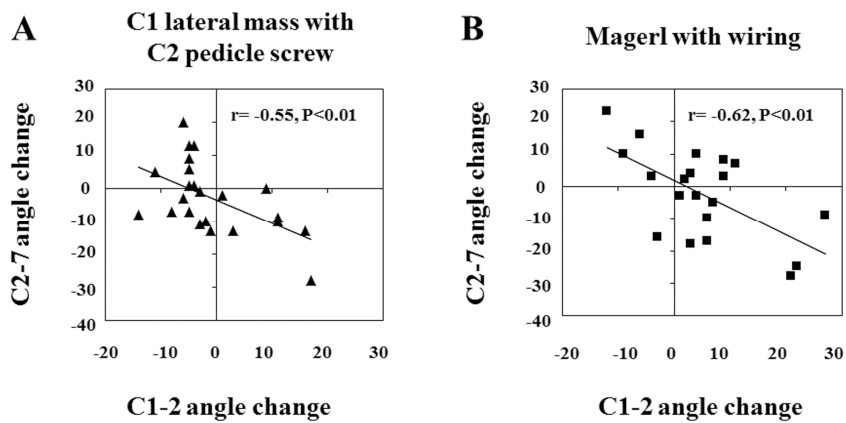


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2 **Fig 2** Correlation between the C1–C2 angle at the final follow–up and the C2–C7 angle change.

3 **A:** C1 lateral mass and C2 pedicle screw group. **B:** Magerl with wiring group.

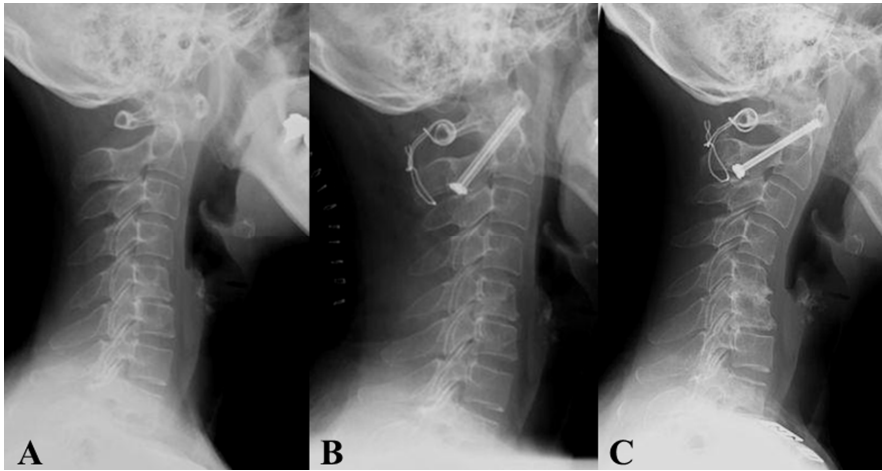
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6 **Fig 3** Correlation between the C1–C2 angle change and C2–C7 angle change. **A:** C1 lateral mass

7 with C2 pedicle screw group. **B:** Magerl with wiring group.



1 **A** **B** **C**

2 **Fig 4** A 42-year-old rheumatoid arthritis woman with a preoperative C1–C2 angle of 27° (**A**).
3 The C1–C2 angle after surgery was increased to 36° after the Magerl procedure combined with
4 Gallie wiring technique (**B**). Increased kyphotic change in the C2–C7 angle was observed at 7
5 years follow-up (**C**).

Table 1. Pre- and Postoperative atlantoaxial interval (ADI) and space available for the spinal cord (SAC)

	Preop	Postop	Final	P value		
				Preop to Postop	Postop to Final	Preop to Final
ADI (mm)						
C1 lateral mass with C2 pedicle screw	8.5 ± 3.1	1.6 ± 1.2	2.0 ± 1.6	<0.0001	1.0	<0.0001
Magerl group with wiring	8.1 ± 3.1	2.5 ± 2.5	2.8 ± 2.1	<0.0001	1.0	<0.0001
SAC (mm)						
C1 lateral mass with C2 pedicle screw	12.2 ± 3.6	19.1 ± 4.4	18.1 ± 4.5	<0.0001	1.0	<0.0001
Magerl group with wiring	13.9 ± 3.7	19.4 ± 3.1	19.4 ± 3.1	<0.0001	1.0	<0.0001

The values are given as the average and the standard deviation.

Table 2. Radiographic Parameters

	Preop	Postop	Final	P value		
				Preop to Postop	Postop to Final	Preop to Final
C1-C2 angle (°)						
C1 lateral mass with C2 pedicle screw	19.1 ± 10.9	19.0 ± 16.0	18.5 ± 6.4	0.48	0.19	0.36
Magerl group with wiring	23.4 ± 11.7	28.3 ± 7.8	28.5 ± 6.2	0.02	0.43	0.02
O-C1 angle (°)						
C1 lateral mass with C2 pedicle screw	6.7 ± 6.1	5.6 ± 5.0	6.1 ± 4.6	0.16	0.34	0.28
Magerl group with wiring	4.8 ± 10.4	2.1 ± 4.6	5.1 ± 6.6	0.12	0.10	0.32
C2-C3 angle (°)						
C1 lateral mass with C2 pedicle screw	2.8 ± 9.4	3.8 ± 8.4	3.0 ± 10.3	0.12	0.21	0.45
Magerl group with wiring	2.8 ± 5.0	0.7 ± 5.6	0.6 ± 6.7	0.11	0.48	0.13
C2-C7 angle (°)						
C1 lateral mass with C2 pedicle screw	19.6 ± 13.8	21.9 ± 14.7	16.3 ± 10.8	0.15	0.06	0.08
Magerl group with wiring	8.9 ± 9.4	10.5 ± 15.1	6.5 ± 14.6	0.30	0.10	0.22

The values are given as the average and the standard deviation.