Subaxial sagittal alignment after atlantoaxial fixation techniques

Shigeki Oshima, MD[1], Hideki Sudo, MD,[2] Manabu Ito, MD,[2] Kuniyoshi Abumi, MD[3]

[1]Hokkaido Orthopaedic Memorial Hospital, Hokkaido University Graduate School of Medicine, Sapporo, Japan

Hiragishi 7-13, Toyohira-ku, Sapporo, Hokkaido 062-0937, Japan

[2]Department of Advanced Medicine for Spine and Spinal Cord Disorders, Hokkaido University Graduate School of Medicine Sapporo, Japan

North-15, West-7, Kita-ku, Sapporo, Hokkaido 060-8638, Japan

[3]Sapporo Orthopaedic Hospital, Sapporo, Japan

Hassamu 13-4, Nishi-ku, Sapporo, Hokkaido 063-0833, Japan

Correspondence and reprint requests to:

Hideki Sudo, MD, PhD

Department of Advanced Medicine for Spine and Spinal Cord Disorders, Hokkaido University Graduate School of Medicine

North-15, West-7, Kita-ku, Sapporo, Hokkaido 060-8638, Japan

Tel: 81-11-706-5934 Fax: 81-11-706-6054

Email: hidekisudo@yahoo.co.jp

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Running head: Subaxial sagittal alignment

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

Abstract

Study Design: Retrospective clinical case series.

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

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

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

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

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

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

Introduction

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

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

Materials and Methods

Patient demographics

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

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

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

Between 1992 and 2008, 22 patients underwent the Magerl procedure combined with Gallie[3] or Brooks–Jenkins[2] wiring technique by the same surgeon. Of these, two female patients with RA who underwent concomitant subaxial laminoplasty were excluded, and the remaining 20 patients [men, 8; women, 12; average age at surgery, 45.5 years (range, 12–71 years); mean follow-up period was 88.6 months (range, 24–180)] were evaluated as the Magerl with wiring group. The causes of C1–C2 subluxation were RA (n = 13), os odontoideum (n = 4), and trauma (*n* = 3).

Surgical techniques

C1-LMS procedure

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

Magerl with wiring procedure

In the same manner as used in the C1-LMS procedure, a Mayfield head holder was used to attempt reduction of C1–C2 subluxation before surgery. Cannulated screws were placed for bilateral transarticular fixation under lateral fluoroscopic guidance.[1, 18] After screw placement, the Gallie [3] or Brooks–Jenkins[2] wiring method was used to fix an iliac bone graft.

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

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.

Results

Patient Demographics

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

Radiological parameters

ADI and SAC

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

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

C1-C2 angle

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

O–C1 and C2–C3 angle

There was no significant change between the pre- and postoperative O–C1 angle in either group. Similarly, no significant difference was observed in the C2–C3 angle change in either group (Table 2).

C2–C7 angle

The average C2–C7 angle only showed a slight increase from 19.6° to 21.9° in the C1-LMS group and 8.9° to 10.5° in the Magerl with wiring group after surgery. Although significant differences were observed, this angle decreased at final follow-up relative to the preoperative angles in both groups (Table 2).

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

We further analyzed the association between the C1–2 and C2–7 angle. There was no statistically significant correlation between the C1–C2 angle at the final follow-up and C2–C7 angle change (angle at final follow-up–preoperative angle) in either the C1-LMS group ($r = -0.05$, $P = 0.84$) (Fig. 2a) or Magerl with wiring group ($r = -0.13$, $P = 0.59$) (Fig. 2b). These results suggest that the magnitude of postoperative reduction in the C2–C7 angle did not depend on the absolute value of the postoperative C1–C2 angle in either procedure.

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

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

Discussion

Many reports on C1–C2 posterior fusion procedures have described surgical techniques, improvement in clinical symptoms, and perioperative complications.[4, 6, 19, 20] However, only a few studies have focused on the association between C1–C2 fixation angle and postoperative subaxial sagittal alignment change.[13-16] Yoshimoto et al.[16] documented that there was a linear correlation between an increase in C1–C2 lordosis and a decrease in C2–C7 lordosis after C1–C2 arthrodesis by wiring alone, the Magerl procedure combined with wiring, or the Halifax clamp procedure. They concluded that in any type of surgery, C1–C2 fixation in the hyperlordotic position would lead to postoperative subaxial kyphosis. Ishii et al.[13] documented that excessive correction of the C1–C2 angle is likely to cause cervical lordosis and development of postoperative subaxial subluxations in rheumatoid arthritis. In the current study, we first compared the postoperative C2–C7 sagittal angle change between the C1-LMS and Magerl with wiring procedures. Our results were consistent with those of previous reports describing a negative linear correlation between the perioperative change in the C1–C2 and C2–C7 sagittal angles.

In this study, significant corrections in postoperative ADI and SAC were observed in both groups. However, the average postoperative C1–C2 sagittal angles were more lordotic in the Magerl with wiring group than in the C1-LMS group. These results suggest that both the C1-LMS and Magerl with wiring procedures provide acceptable reduction of C1–C2 translation, whereas it is easier to control the C1–C2 fixation angle in the C1-LMS procedure than in the Magerl and wiring technique. Indeed, both techniques may fix the C1–C2 joint in the surgeon's desired position. However, in the Magerl technique, the fixation angle strongly depends on the preoperative neck position,[16] whereas the C1-LMS procedure is effective in controlling C1–C2 sagittal alignment during surgery. In addition, because the posterior wiring techniques used to supplement the Magerl procedure depend primarily on the compression force between grafted bone and the C1–C2 laminae, this procedure has a tendency to fix the C1–C2 joint in the hyperlordotic position.[13] Matsumoto et al.[21] recommended the application of structural interlaminar spacers, such as ceramic spacers or titanium mesh cages, instead of autologous bone that can maintain proper cervical alignment for posterior atlantoaxial transarticular screw fixation.

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

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

Conclusions

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

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Figure legends

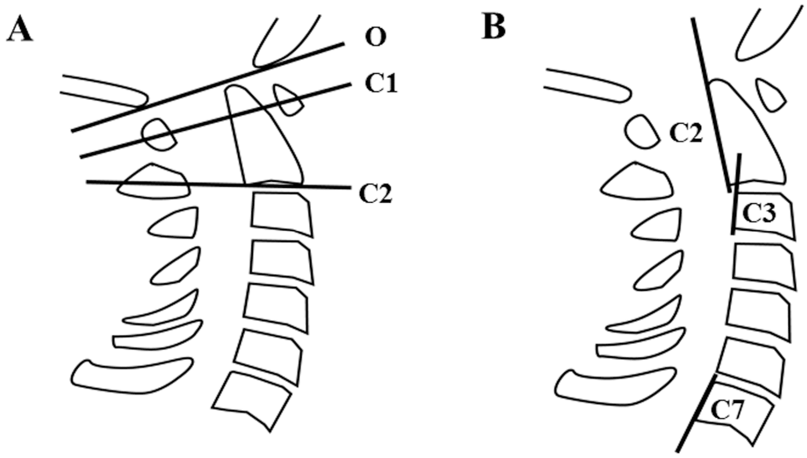

Fig 1 Schematic drawings of radiological parameters. **A:** The O–C1 angle was measured between the McRae's line and the line passing through the center of the C1 anterior arch and the center of the C1 posterior arch. The C1–C2 angle was measured between the line passing through the centers of the C1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

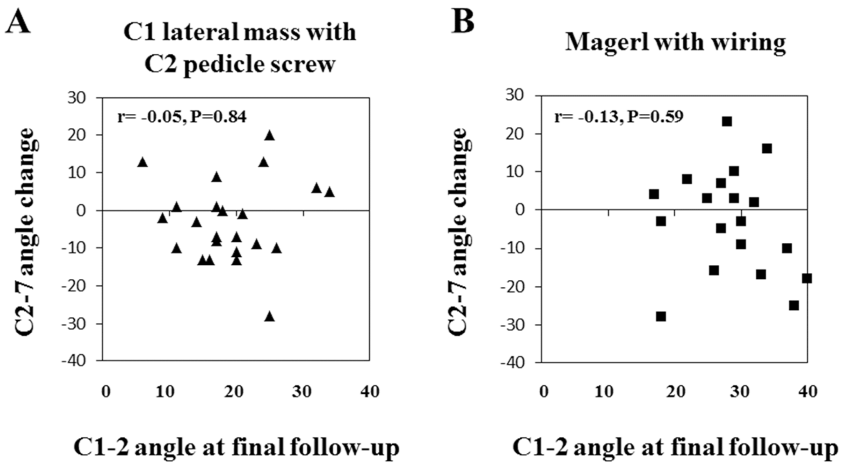

Fig 2 Correlation between the C1–C2 angle at the final follow–up and the C2–C7 angle change. **A:** C1 lateral mass and C2 pedicle screw group. **B:** Magerl with wiring group.

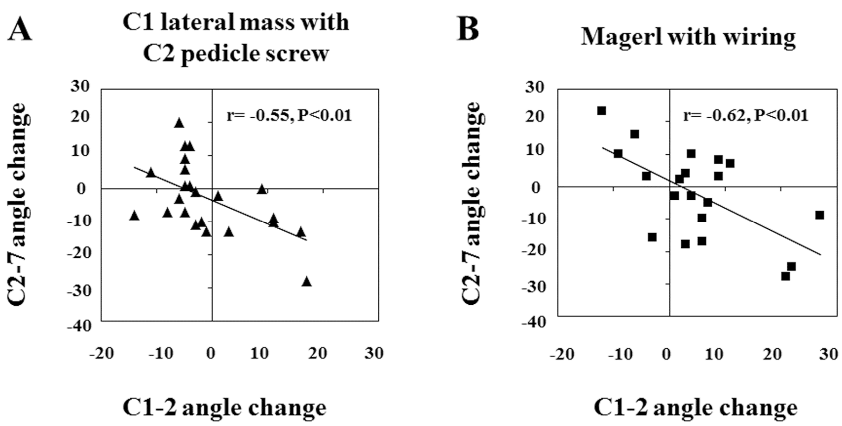

Fig 3 Correlation between the C1–C2 angle change and C2–C7 angle change. **A:** C1 lateral mass with C2 pedicle screw group. **B:** Magerl with wiring group.

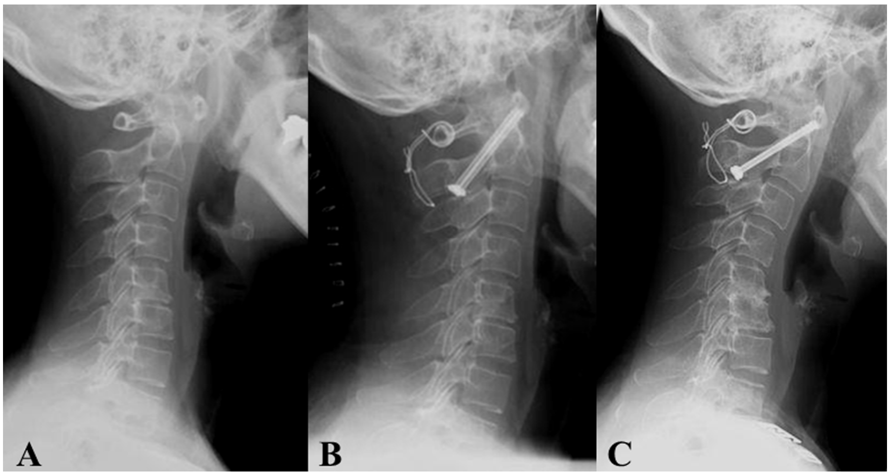

Fig 4 A 42-year-old rheumatoid arthritis woman with a preoperative C1–C2 angle of 27º (**A**). The C1–C2 angle after surgery was increased to 36º after the Magerl procedure combined with Gallie wiring technique (**B**). Increased kyphotic change in the C2–C7 angle was observed at 7 years follow-up (**C**).

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 (º)						
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 (º)						
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 (º)						
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 (º)						
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.