Eur Spine J (2014) 23:1067–1076
DOI 10.1007/s00586-013-3125-6

ORIGINAL ARTICLE

Spine surgeon's kinematics during discectomy, part II: Operating table height and visualization methods, including microscope

Jeong Yoon Park · Kyung Hyun Kim · Sung Uk Kuh · Dong Kyu Chin · Keun Su Kim · Yong Eun Cho

Received: 13 August 2013 / Revised: 27 November 2013 / Accepted: 29 November 2013 / Published online: 24 December 2013

Abstract
Purpose Surgeon spine angle during surgery was studied ergonomically and the kinematics of the surgeon's spine was related with musculoskeletal fatigue and pain. Spine angles varied depending on operation table height and visualization method, and in a previous paper we showed that the use of a loupe and a table height at the midpoint between the umbilicus and the sternum are optimal for reducing musculoskeletal loading. However, no studies have previously included a microscope as a possible visualization method. The objective of this study is to assess differences in surgeon spine angles depending on operating table height and visualization method, including microscope.
Materials and methods We enrolled 18 experienced spine surgeons for this study, who each performed a discectomy using a spine surgery simulator. Three different methods were used to visualize the surgical field (naked eye, loupe, microscope) and three different operating table heights (anterior superior iliac spine, umbilicus, the midpoint between the umbilicus and the sternum) were studied. Whole spine angles were compared for three different views during the discectomy simulation: midline, ipsilateral, and contralateral. A 16-camera optoelectronic motion analysis system was used, and 16 markers were placed from the head to the pelvis. Lumbar lordosis, thoracic kyphosis, cervical lordosis, and occipital angle were compared between the different operating table heights and visualization methods as well as a natural standing position.
Results Whole spine angles differed significantly depending on visualization method. All parameters were closer to natural standing values when discectomy was performed with a microscope, and there were no differences between the naked eye and the loupe. Whole spine angles were also found to differ from the natural standing position depending on operating table height, and became closer to natural standing position values as the operating table height increased, independent of the visualization method. When using a microscope, lumbar lordosis, thoracic kyphosis, and cervical lordosis showed no differences according to table heights above the umbilicus.
Conclusion This study suggests that the use of a microscope and a table height above the umbilicus are optimal for reducing surgeon musculoskeletal fatigue.

Keywords Spine · Surgeon · Kinematics · Discectomy

Introduction

The ergonomics of surgery has become an important issue since the introduction of laparoscopic surgery, which is now commonly used because of its minimally invasive nature. In contrast to open surgery, laparoscopic surgery usually requires longer instruments [7, 8], and is associated with increased musculoskeletal discomfort and fatigue of the lower back, neck, and shoulder, eventually resulting in muscle pain [1–4]. The pain experienced by the surgeon is usually concentrated at the body axis, while the main purpose of spine surgery is to resolve the axial pain of the patient [1, 2]. Many spine surgeons (including the authors)

J. Y. Park · K. H. Kim · S. U. Kuh · D. K. Chin · K. S. Kim · Y. E. Cho (✉)
Department of Neurosurgery, Gangnam Severance Hospital, The Spine and Spinal Cord Institute, Yonsei University College of Medicine, 211 Eonju-ro, Gangnam-gu, Seoul 135-720, South Korea
e-mail: yecho@yuhs.ac

have also experienced neck and back pain during and after spine surgery. To determine the most ergonomic environment for spine surgery, we previously studied surgeon kinematics during discectomy using a three-dimensional (3-D) motion analysis system [2].

Our previous paper found that the whole spine angles of surgeons during spine surgery depended significantly on operation table height and visualization method, and we concluded that the use of a loupe and a table height at the midpoint between the umbilicus (U) and the sternum are optimal for reducing surgeon musculoskeletal loading during discectomy [2]. However, this paper did not include an operating microscope as a visualization method. In 1977, Yasargil introduced the microscope to spine surgery, and it has since become a mainstay of modern spine surgery due to significant magnification and illumination advantages [5, 6].

The current study is a follow-up on surgery kinematics that includes an operating microscope as a visualization method [2]. The aim of this study is to analyze spine angles under different ergonomic conditions faced by spine surgeons during discectomy, and to investigate differences in head and whole spine motion patterns and angles with respect to operation table height and visualization methods (including microscope) using a noninvasive 3-D motion analysis system.

Materials and methods

Subjects

We used a randomized crossover design to examine the relationship between head and whole spine angles depending on visualization method and operating table height during discectomy. The study protocol was reviewed and approved by the institutional review board of Gangnam Severance Hospital, Yonsei University College of Medicine (No. 3-2011-0127). A cohort of 18 experienced spine surgeons was enrolled. All of these surgeons had more than 4 years of experience conducting spine surgeries.

Experimental setup

Eighteen experienced spine surgeons performed discectomy using a spine surgery simulator (Spine Surgery Simulator 1-Lumbo-sacral, CREAPLAST, Verton, FR) with three visualization methods (naked eye, loupe, and microscope) (Fig. 1) and three operating table heights [anterior superior iliac spine (ASIS), umbilicus, midpoint between the umbilicus and sternum (U-S)]. Whole spine and head motions and angles were examined from three different views during the simulations: the midline, ipsilateral, and contralateral views (Fig. 2). Data was acquired

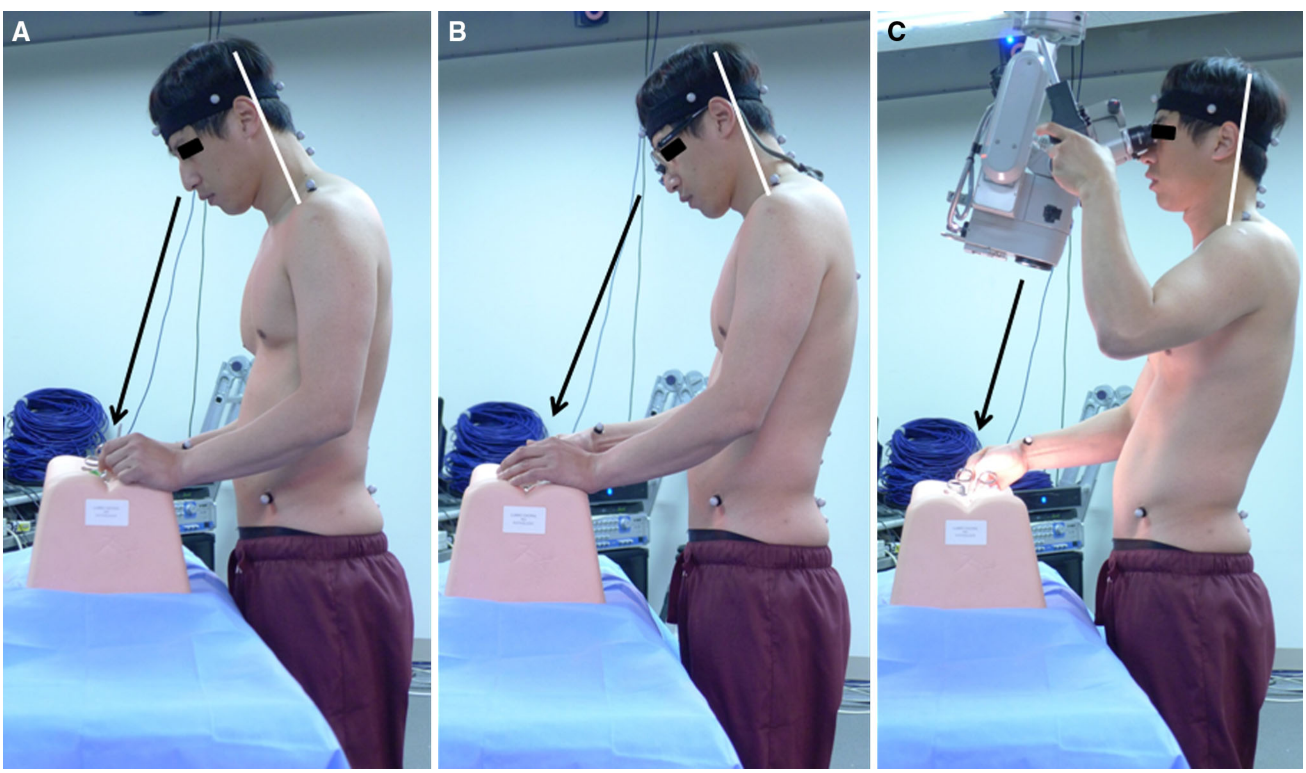

Fig. 1 The three methods used to visualize the surgical field: naked eye (**a**), loupe (**b**), and operating microscope (**c**)

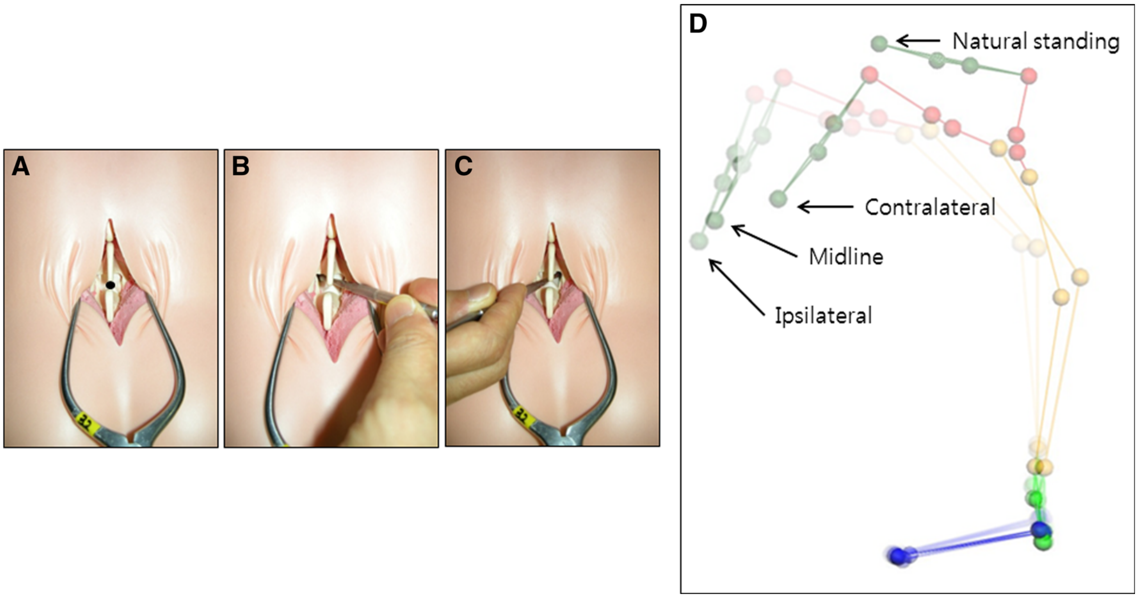

Fig. 2 Spine surgeons performed discectomy using a spine surgery simulator (Spine Surgery Simulator 1-Lumbo-sacral, CREAPLAST, Verton, FR) under three views: midline (**a**), ipsilateral (**b**), and contralateral (**c**). The 3-D model of the motion analysis system from the three different viewpoints is shown in **d**

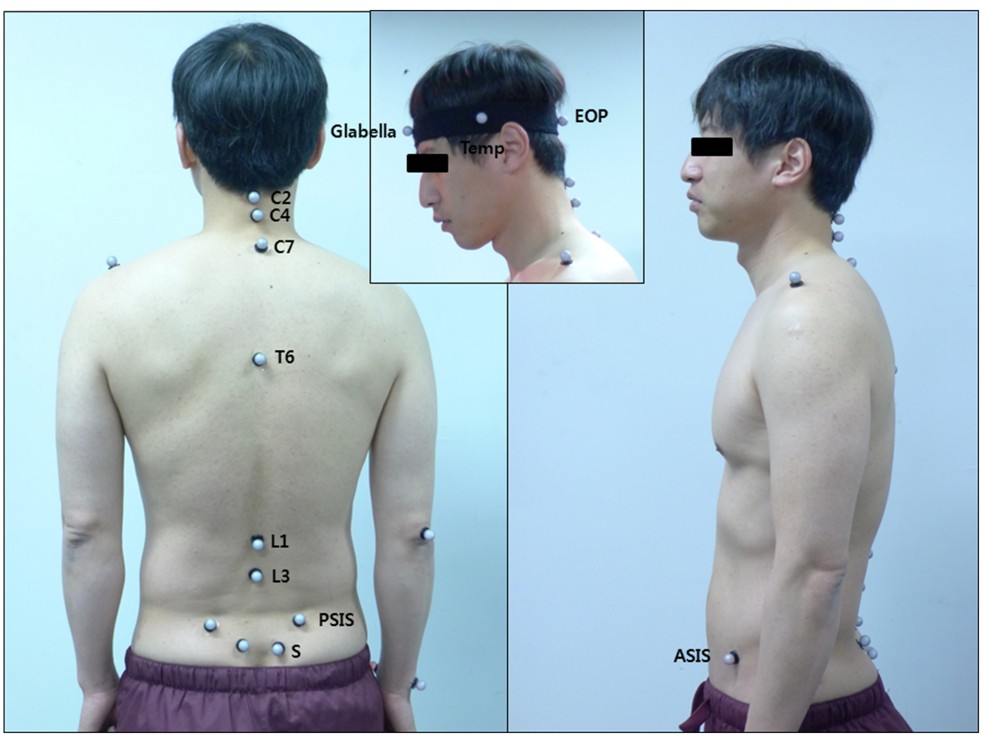

Fig. 3 Sixteen markers were placed on the skin from the head to the pelvis: one on the *glabella*, two on the most prominent parts of the temporal line (*Temp*), one on the external occipital protuberance (*EOP*), six on the spinous processes of the cervical vertebrae (*C2*, *C4*, *C7*, *T6*, *L1*, and *L3*), two on the most prominent part of the lateral sacral crest (*S*), two on the posterior superior iliac spine (*PSIS*), and two on the anterior superior iliac spine (*ASIS*)

using a Vicon 3-D motion analysis 16-camera system (Model MX-T40, Vicon Motion Systems, Oxford, UK) operating at a sample rate of 100 Hz.

Sixteen markers were placed on the skin from the head to the pelvis (Fig. 3): one on the glabella, two on the most prominent parts of the temporal line (Temp), one on the

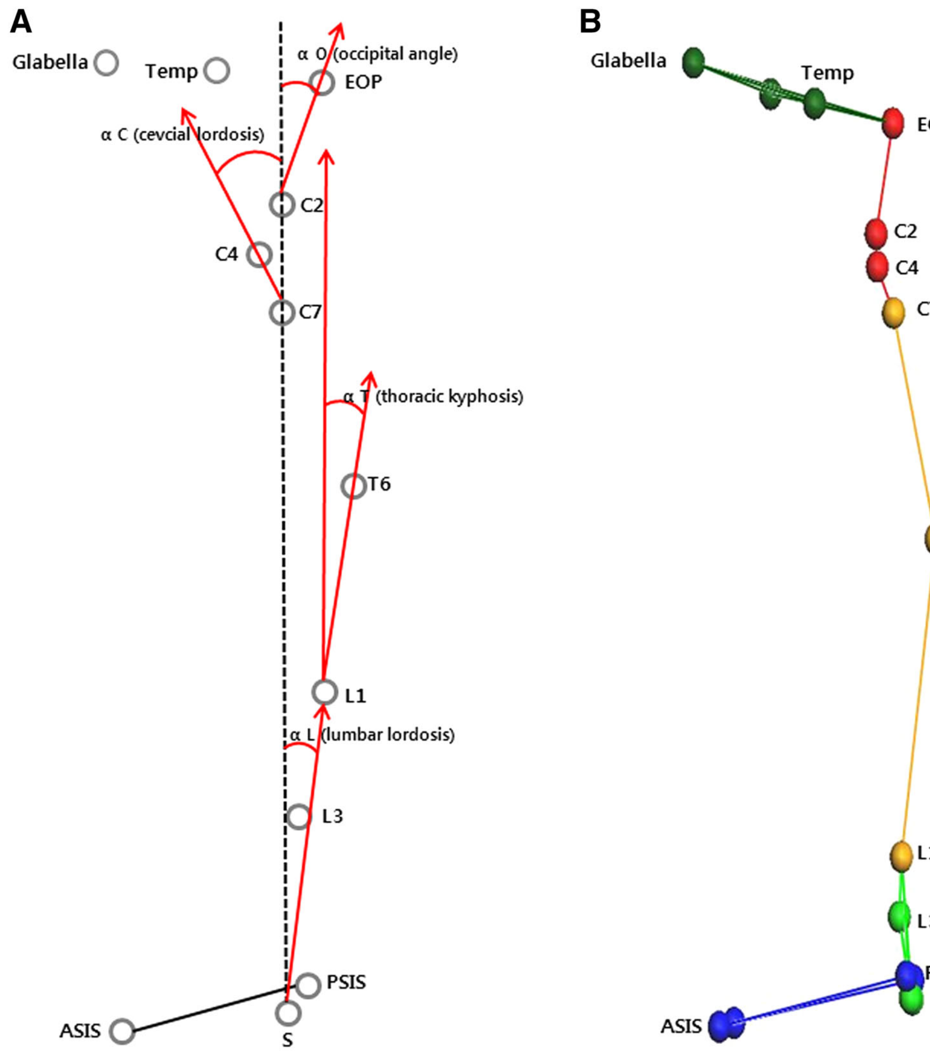

Fig. 4 Lumbar lordosis (αL) was defined as the angle formed by the intersection between the *line from C2 to S* and the *line from L1 to S*. Thoracic kyphosis (αT) was defined as the angle formed by the intersection between the *line from C2 to S* and the *line from L1 to T6*. Cervical lordosis (αC) was defined as the angle formed by the intersection between the *line from C2 to S* and the *line from C7 to C4*. Occipital angle (αO) was defined as the angle formed by the intersection between the *line from C2 to S* and the *line from C2 to EOP* (**a**). A skin marker on a 3-D model from the Vicon 3 dimensional motion analysis 16-camera system (Model MX-T40, Vicon Motion Systems, Oxford, UK) is also shown in **b**

external occipital protuberance (EOP), three on spinous processes of the cervical vertebrae (C2, C4, and C7), one on the spinous process of T6, two on the spinous processes of L1 and L3, two on the most prominent parts of the lateral sacral crest (S), two on the posterior superior iliac spine, and two on the ASIS.

Modeling and data processing

Three-dimensional data from the optoelectronic system was processed using Vicon Nexus 1.7 software (Vicon Motion Systems, Oxford, UK). Lumbar lordosis (αL) was defined as the angle formed by the intersection between the line joining C2 and S and the line joining L1 and S; thoracic kyphosis (αT) as the angle formed by the intersection between the line joining C2 and S and the line joining L1 and T6; cervical lordosis (αC) as the angle formed by the intersection between the line joining C2 and S and the line joining C7 and C4; and the occipital angle (αO) as the angle formed by the intersection between the line joining C2 and S and line joining C2 and EOP (Fig. 4). We measured αL, αT, αC, and αO in the natural standing position, when the naked eye, loupe, and microscope were used to visualize the surgical field (Fig. 1), and at three operating table heights (ASIS, U, and U-S) under three surgical views (midline, ipsilateral, and contralateral) (Fig. 2).

Mean values for all parameters were computed, and SPSS for Windows (Version 15.0K; SPSS, Chicago, IL,

Table 1 The mean values and the standard deviations of all parameters

	Anterior superior iliac spine			Umbilicus			Midpoint between umbilicus and sternum		
	Contralateral	Midline	Ipsilateral	Contralateral	Midline	Ipsilateral	Contralateral	Midline	Ipsilateral
Lumbar lordosis (1.86 ± 2.33)[†]									
Naked Eye	13.05 ± 5.26	14.57 ± 3.92	19.21 ± 2.92	11.95 ± 3.20	12.24 ± 2.80	17.54 ± 2.68*, [b]	9.80 ± 2.84*, [b]	9.96 ± 1.78*, [b]	15.80 ± 2.69*, [b]
Loupe	14.41 ± 4.61	14.94 ± 3.67	18.44 ± 3.07	12.72 ± 5.30	12.29 ± 3.26	16.94 ± 3.79	11.27 ± 3.66*, [b]	11.52 ± 3.26*, [b]	14.92 ± 2.52*, [b]
Microscope*[a]	3.95 ± 2.64	5.26 ± 4.11	5.79 ± 2.50	2.69 ± 2.47	3.00 ± 2.01**, [b]	2.74 ± 1.53*, [b]	3.04 ± 4.00	2.58 ± 2.19*, [b]	2.86 ± 2.39**, [b]
Thoracic kyphosis (10.92 ± 1.46)[†]									
Naked Eye	16.23 ± 1.64	17.18 ± 2.06	16.44 ± 1.69	16.76 ± 2.39	17.38 ± 2.00	16.67 ± 2.72	16.12 ± 2.27	16.51 ± 1.89*, [b]	16.39 ± 1.46
Loupe	17.31 ± 2.01	17.24 ± 1.83	16.61 ± 1.08	16.83 ± 1.80	17.24 ± 1.85	16.64 ± 1.80	16.92 ± 2.05	17.14 ± 1.85	17.24 ± 1.66**[b]
Microscope*[a]	13.41 ± 2.84	13.08 ± 1.76	12.65 ± 2.22	11.99 ± 0.93*, [b]	12.87 ± 1.60	12.04 ± 1.59	12.03 ± 2.10*, [b]	12.14 ± 1.62*, [b]	11.92 ± 1.66
Cervical lordosis (−24.64 ± 4.28)[†]									
Naked Eye	–			36.34 ± 6.48	−39.52 ± 6.31	−43.29 ± 5.01	−36.16 ± 5.14	−37.25 ± 5.10*, [b]	−41.54 ± 3.74*[b]
–				34.03 ± 4.50**, [b]	−35.04 ± 3.76*, [b]	−39.87 ± 4.89*, [b]			
Loupe	–			39.51 ± 5.97	−39.99 ± 5.71	−42.22 ± 5.28	−37.12 ± 6.54*, [b]	−37.28 ± 5.03*, [b]	−41.10 ± 4.68
–				35.90 ± 5.08*, [b]	−36.21 ± 4.85*, [b]	−39.59 ± 3.35**, [b]			
Microscope*[a]	–			25.93 ± 5.79	−26.79 ± 6.34	−26.61 ± 5.43	−24.02 ± 3.77**, [b]	−25.65 ± 3.79	−23.69 ± 2.56*, [b]
−25.41 ± 6.21	–			25.26 ± 3.80**, [b]	−25.68 ± 4.01				
Occipital angle (16.04 ± 2.87)[†]									
Naked Eye	–			20.67 ± 8.67	−24.22 ± 9.90	−29.10 ± 9.97	−19.53 ± 9.40	−21.65 ± 8.33*, [b]	−26.57 ± 8.52*, [b]
–				14.43 ± 7.88*, [b]	−16.67 ± 5.87*, [b]	−23.79 ± 7.84*, [b]			
Loupe	–			24.32 ± 6.00	−25.58 ± 6.86	−27.93 ± 6.07	−21.06 ± 4.56*, [b]	−21.78 ± 5.89*, [b]	−26.83 ± 4.19
–				20.17 ± 6.82*, [b]	−21.35 ± 6.53*, [b]	−26.43 ± 3.79**[b]			
Microscope*[a]	0.83 ± 8.37	0.30 ± 7.32	1.10 ± 6.27	5.82 ± 5.72*, [b]	4.24 ± 6.02*, [b]	4.36 ± 7.08*, [b]	6.27 ± 5.29*, [b]	6.33 ± 4.88*, [b]	6.54 ± 3.17*, [b]

* Indicates $p < 0.01$ and ** indicates $p < 0.05$

† Static values

[a] Differences according to methods to see surgical field

[b] Differences according to operating table height

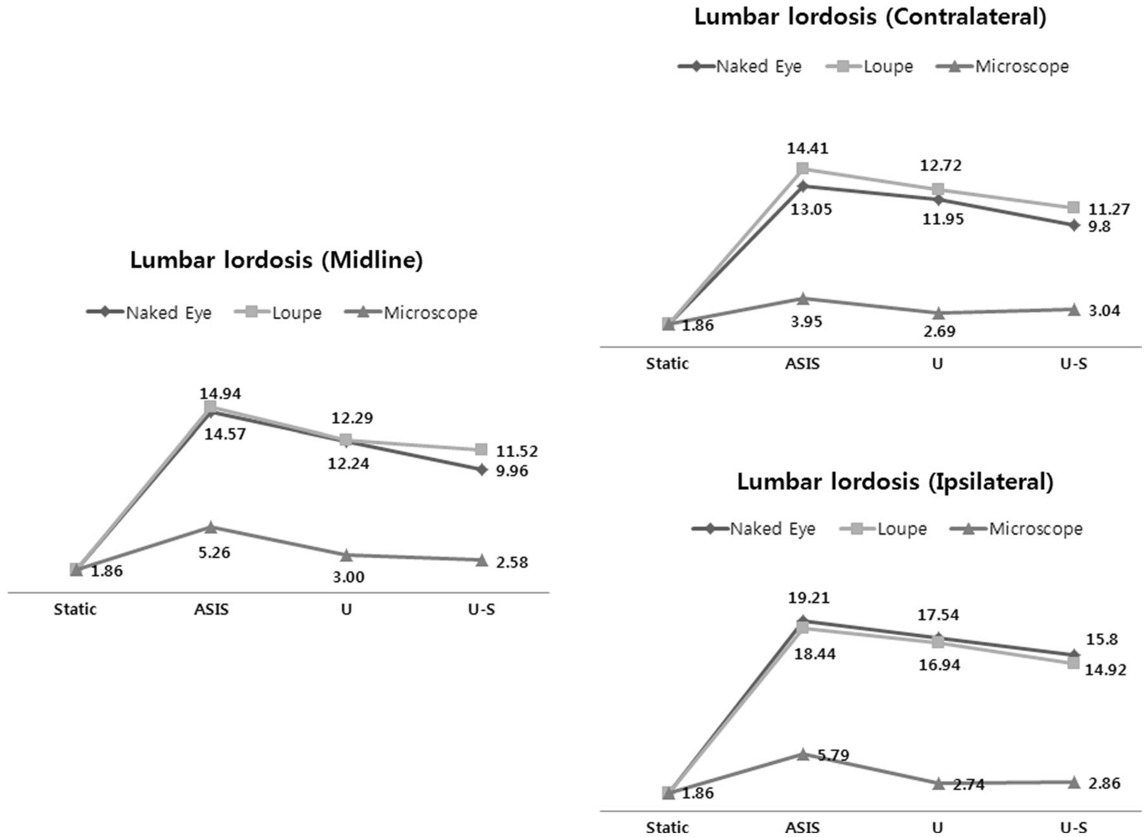

Fig. 5 Lumbar lordosis (αL) measured using the three different visualization methods (naked eye, loupe, microscope), the three different operating table heights (*ASIS* anterior superior iliac spine, *U* umbilicus, *U-S* midpoint between umbilicus and sternum), and the three different viewpoints (midline, ipsilateral, and contralateral)

USA) was used for statistical analysis. A 3 × 3 × 3 (operating table height × methods × tasks) analysis of variance with repeated measures was performed. Kruskal–Wallis ANOVA and the Friedman test were used to compare the nine variations (operating table height × methods × tasks) with natural standing position, and p values of <0.05 were considered significant.

Results

The mean values and standard deviations of all studied parameters are listed in Table 1. Head and whole spine angles were significantly different depending on visualization method (naked eye, loupe, and microscope) in all surgical field views (midline, ipsilateral, and contralateral). The head and whole spine angles differed significantly for each view with or without a microscope (Table 1). All parameters (lumbar lordosis αL, cervical lordosis αC, occipital angle αO, thoracic kyphosis αT) were closer to the natural standing position with the use of a microscope ($p < 0.01$) (Figs. 5, 6, 7, 8; Table 1). The naked eye and loupe showed no differences.

All parameters also showed differences depending on operation table height. As the operating table height increased, all parameters were closer to the natural standing position under all three surgical field views (midline, ipsilateral, and contralateral) and using all visualization methods except the microscope (Figs. 5, 6, 7, 8; Table 1). With a microscope, all parameters were closer to the natural standing position as the operating table height increased, but lumbar lordosis (αL), cervical lordosis (αC), and thoracic kyphosis (αT) did not show any difference between operating table height at the umbilicus and at the midpoint between the U-S (Figs. 5, 6, 8; Table 1).

Discussion

Since the rise of laparoscopic surgery, previous studies on the ergonomics of surgeons have usually focused on leg fatigue, large working areas, extreme movements of the upper limbs and wrists, and stiffness of the neck [3, 4, 7, 8]. No study has been conducted on the surgeon's spine or head motion, although both are associated with complaints of axial musculoskeletal discomfort and fatigue, including

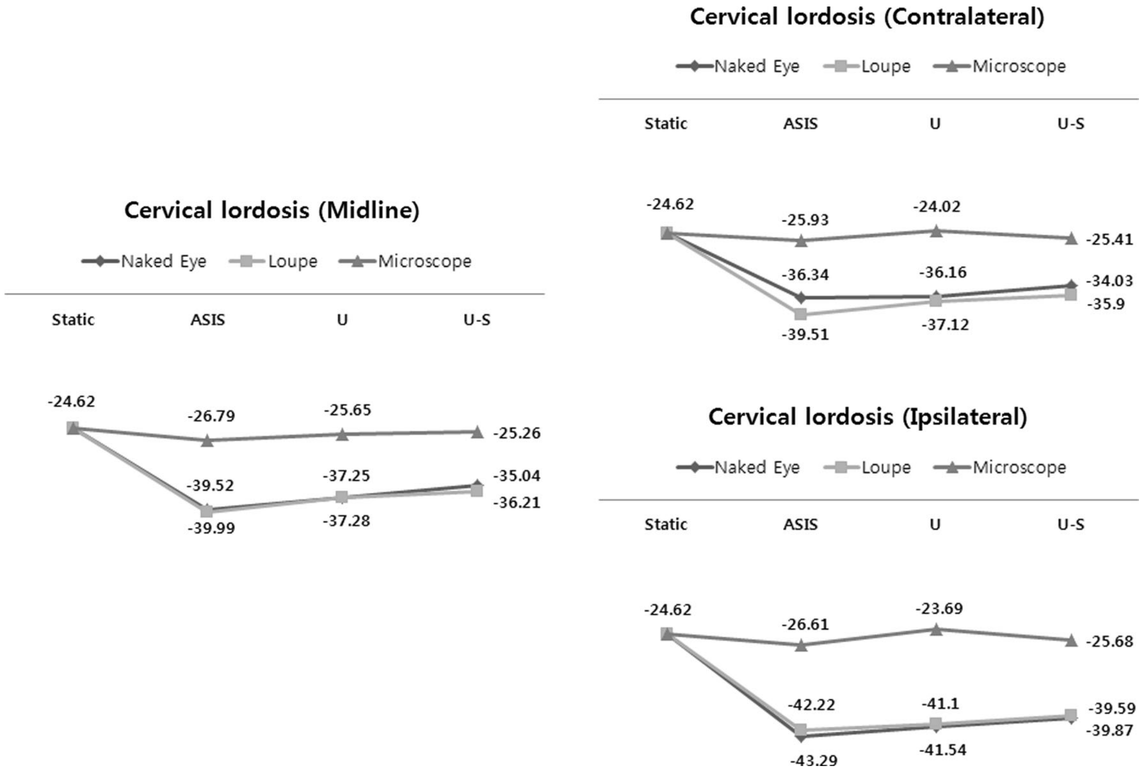

Fig. 6 Cervical lordosis (αC) measured using the three different visualization methods (naked eye, loupe, microscope), the three different operating table heights (*ASIS* anterior superior iliac spine, *U* umbilicus, *U-S* midpoint between umbilicus and sternum), and the three different viewpoints (midline, ipsilateral, and contralateral)

in the lower back, neck, and shoulder [3, 9]. Our previous study was the first to analyze the motion and arrangement of the whole spine and head during surgery under different operating parameters. In that study, we found that the optimal table height was the midpoint between the umbilicus and the sternum, and spine operation with loupe is also good in aspect of whole spine angle [2].

Since 1970s, to use operating microscopes during spine surgery has become increasingly popular since the 1970s, and lumbar microdiscectomy is currently most common procedure performed using a microscope [6]. In a survey of neurosurgeons, 70 % said they used a microscope during lumbar discectomy [10]. With the development of minimally invasive spine surgery techniques, the use of operating microscopes has become more popular and is now an essential technique for spine surgeons. In addition, many spine surgeons experience less neck fatigue when using an operating microscope. However, there have been no studies on surgeon kinematics with the use of operating microscopes. This study showed that the use of a microscope improved all spine and head angles (lumbar lordosis αL, cervical lordosis αC, occipital angle αO, thoracic kyphosis αT) so that they were closer to the natural standing position, which is ergonomically advantageous. Wunderlich et al. [1] also reported that a microscope is the most effective technique with respect to posture and movements of the spine and trunk during otolaryngial sinus surgery.

Our previous study reported that the use of a loupe is better than the naked eye [2]. Branson et al. previously reported that the use of a loupe while performing dental procedures may increase the quality of work and prevent chronic neck and back pain [11–13]. A strong relationship exists between head working angle and neck muscle fatigue, the use of a loupe decreases head tilt angle, reducing spine stress and loading [14]. Different from the previous study, this study found that the naked eye and loupe showed no differences (Figs. 5, 6, 7, 8; Table 1), though the previous study used a flip-up loupe while this study used an in-lens loupe (Fig. 9), which can influence head tilt angle. On the other hand, the magnification is fixed with an in-lens loupe, while it can be adjusted in a flip-up loupe (Fig. 9). Because of the adjustment possibility, we think that flip-up loupes are superior to in-lens loupes.

In terms of operating table height, the optimal table height for laparoscopic surgery should position the laparoscopic instrument handles close to the surgeon's elbow level to minimize discomfort and upper arm and shoulder muscle strain [15, 16]. Usually, the midpoint between the

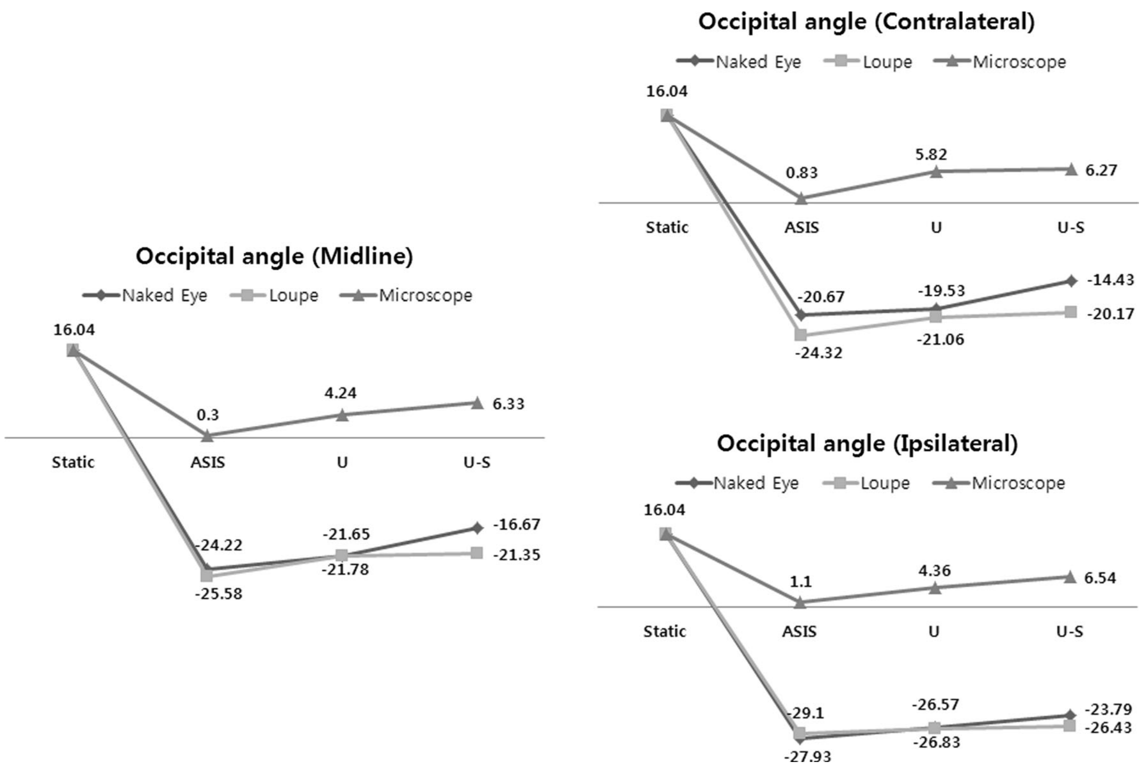

Fig. 7 Occipital angles (αO) measured using the three different visualization methods (naked eye, loupe, microscope), the three different operating table heights (*ASIS* anterior superior iliac spine, *U* umbilicus, *U-S* midpoint between umbilicus and sternum), and the three different viewpoints (midline, ipsilateral, and contralateral)

umbilicus and the sternum (U-S) is located at elbow level [2]. With the naked eye and a loupe, we found that higher operating table heights were ergonomically superior up until the midpoint between the umbilicus and the sternum. However, with a microscope, lumbar lordosis (αL), cervical lordosis (αC), and thoracic kyphosis (αT) did not show any differences between operating table height at the umbilicus and at the midpoint between the umbilicus and the sternum (U-S) (Figs. 5, 6, 8; Table 1). Adjustments in the microscope eyepiece allow for more comfortable spine angles, and so operating table heights above the umbilicus showed no differences in spine angle.

Based on our findings, we recommend that the operating table should be positioned to a height that is midway between the umbilicus and the sternum during spine surgery with or without loupe. When using a loupe, flip-up loupes are superior as long as weight is not an issue. Among the various visualization methods, microscopes are ergonomically superior with respect to spine and head angle.

This study has several limitations. The lumbar lordosis (αL), cervical lordosis (αC), occipital angle (αO), and thoracic kyphosis as defined in this study differ from the real lumbar lordosis, cervical lordosis, occipital angle, and thoracic kyphosis. In order to determine spine and head angles using the 3-D optoelectronic system, we selected marker attachment sites after considering whole spine radiographs and skin surface anatomy. To determine precise cervical, thoracic, and lumbar angles, spine endplate angles are needed, but it is impossible to measure endplate angles in real time during spine surgery simulation. Although the cervical, thoracic, and lumbar angles using the 3-D data obtained from optoelectronic systems may differ from the real bony spine angles, they can reflect changes in spine angles during surgery simulations. To determine more precisely the spinal and occipital angles, new methods which can measure exact spine motion and angles in real time are needed.

Conclusions

We suggest that the use of a microscope is beneficial to surgeons during spinal surgery. Without a microscope, higher table heights are ergonomically superior until the table reaches the midpoint between the umbilicus and the sternum. With a microscope, the disadvantages of low table heights can be overcome by microscope adjustments. Our simulations can be used as a guide for young surgeons to protect their own spinal alignment during surgery.

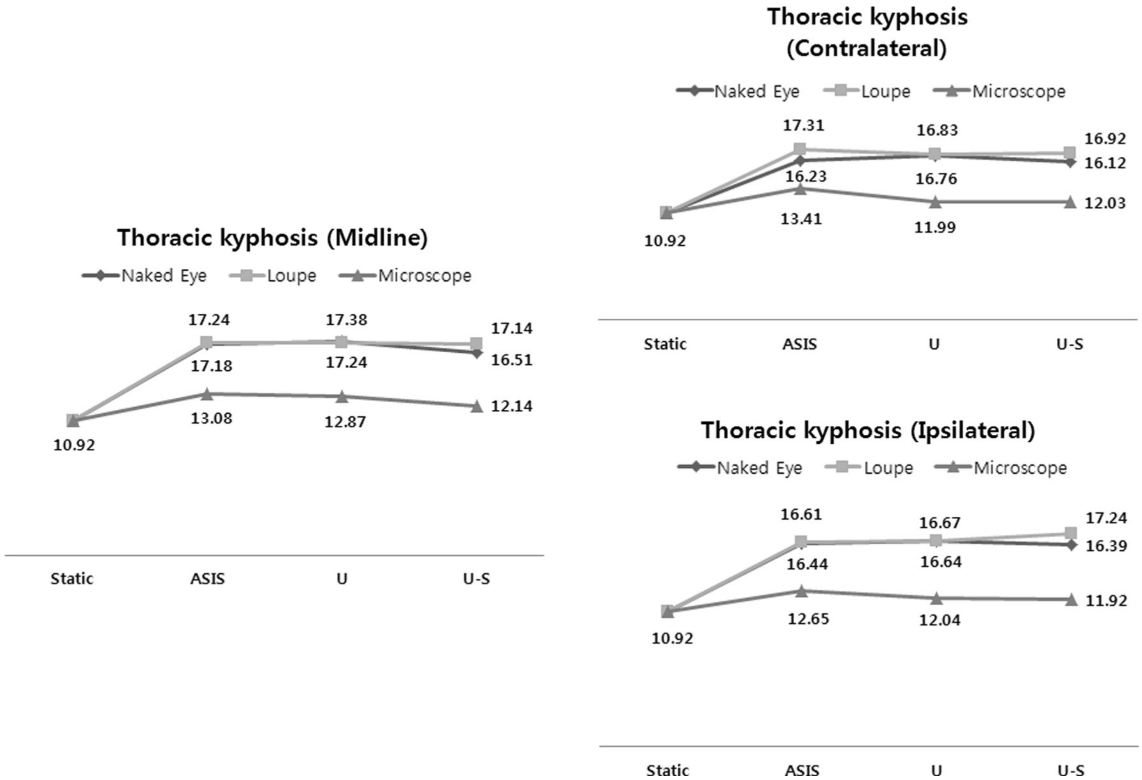

Fig. 8 Thoracic kyphosis (αT) measured using the three different visualization methods (naked eye, loupe, microscope), the three different operating table heights (*ASIS* anterior superior iliac spine, *U* umbilicus, *U-S* midpoint between umbilicus and sternum), and the three different views (midline, ipsilateral, and contralateral)

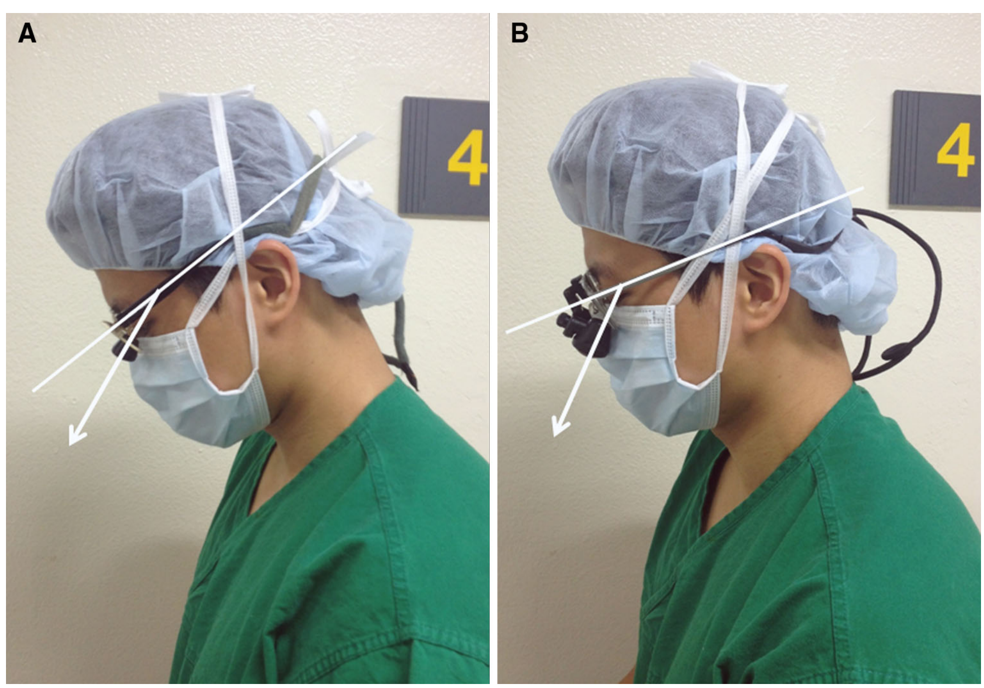

Fig. 9 Eye-magnification component angle according to loupe type: in-lens (**a**) and flip-up (**b**)

Acknowledgments This work is supported by the Technology Innovation Program (10040097) funded by the Ministry of Trade, Industry and Energy Republic of Korea (MOTIE, Korea).

Conflict of interest None.

References

1. Wunderlich M, Jacob R, Stelzig Y, Rüther T, Leyk D (2010) Analysis of spinal stress during surgery in otolaryngology. HNO 58:791–798
2. Park JY, Kim KH, Kuh SU, Chin DK, Cho YE (2012) Spine surgeon's kinematics during discectomy according to operating table height and the methods to visualize the surgical field. Eur Spine J 21:2704–2712
3. van Det MJ, Meijerink WJ, Hoff C, Tott ER, Pierie JP (2009) Optimal ergonomics for laparoscopic surgery in minimally invasive surgery suites: a review and guidelines. Surg Endosc 23:1279–1285
4. Kant IJ, de Jong LC, van Rijssen-Moll M, Borm PJ (1992) A survey of static and dynamic work postures of operating room staff. Int Arch Occup Environ Health 63:423–428
5. Shirzadi A, Mukherjee D, Drazin DG, Paff M, Perri B, Mamelak AN, Siddique K (2012) Use of the video telescope operating monitor (VITOM) as an alternative to the operating microscope in spine surgery. Spine 37:1517–1523
6. Postacchini F, Postacchini R (2011) Operative management of lumbar disc herniation: the evolution of knowledge and surgical techniques in the last century. Acta Neurochir Suppl 108:17–21
7. Kranenburg Gossot (2004) Ergonomic problems encountered during video-assisted thoracic surgery. Minim Invasive Ther Allied Technol 13:147–155
8. Lee G, Lee T, Dexter D, Godinez C, Meenaghan N, Catania R, Park A (2009) Ergonomic risk associated with assisting in minimally invasive surgery. Surg Endosc 23:182–188
9. Mirbod SM, Yoshida H, Miyamoto K, Miyashita K, Inaba R, Iwata H (1995) Subjective complaints in orthopedists and general surgeons. Int Arch Occup Environ Health 67:179–186
10. Cenic A, Kachur E (2009) Lumbar discectomy: a national survey of neurosurgeons and literature review. Can J Neurol Sci 36:196–200
11. Branson BG, Bray KK, Gadbury Amyot C, Holt LA, Keselyak NT, Mitchell TV, Williams KB (2004) Effect of magnification lenses on student operator posture. J Dent Educ 68:384–389
12. Mamoun JS (2009) A rationale for the use of high-powered magnification or microscopes in general dentistry. Gen Dent 57:18–26
13. Maggio MP, Villegas H, Blatz MB (2011) The effect of magnification loupes on the performance of preclinical dental students. Quintessence Int 42:45–55
14. Chang BJ (2002) Ergonomic benefits of surgical telescope systems: selection guidelines. J Calif Dent Assoc 30:161–169
15. Berquer R, Smith WD, Davis S (2002) An ergonomic study of the optimum operating table height for laparoscopic surgery. Surg Endosc 16:416–421
16. van Veelen MA, Kazemier G, Koopman J, Goossens RH, Meijer DW (2002) Assessment of the ergonomically optimal operating surface height for laparoscopic surgery. J Laparoendosc Adv Surg Tech A 12:47–52