의학석사 학위논문

하부 경추에서 경추 후궁 나사의 삽입 가능성:

215례의 3차원 컴퓨터 단층촬영 및 시뮬레이션 소프트웨어를 이용한 분석

2013년 2월

서울대학교 대학원

의학과 정형외과학 전공

신상익

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The feasibility of laminar screw placement in the subaxial spine:

analysis using 215 three-dimensional computed tomography scans and simulation software

February, 2013

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Orthopaedic Surgery

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지도교수 **염 진 섭**

이 논문을 의학석사 학위논문으로 제출함.

2012년 12월

서울대학교 대학원

의학과 정형외과학 전공

신 상 익

신상익의 의학석사 학위논문을 인준함.

2012년 12월

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The feasibility of laminar screw placement in the subaxial spine:

analysis using 215 three-dimensional computed tomography scans and simulation software

by

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A thesis submitted in partial fulfillment of
the requirements for the degree of
Master of Science in Medicine
(Orthopaedic Surgery)
in Seoul National University, Seoul, Korea

December, 2012

Approved by thesis committee

Professor ____________________________ Chairman

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Abstract

Purpose : To determine the feasibility of the laminar screw placement in the subaxial cervical spine using a large number of computerized tomography (CT) scans and 3-dimensional screw trajectory software.

Methods : CT scans of 215 consecutive patients were examined, for a total of 430 screws at each level of the subaxial cervical spine. Screw entry points and trajectories were analyzed using 3-dimensional screw trajectory software which has a simulation function similar to preoperative planning software. We simulated the placement of 3.5 mm subaxial (C3-C7) cervical laminar screws. Unilateral and bilateral screws were simulated, and their success rates were evaluated at each level of the subaxial cervical spine. Successful screw placement was defined as insertion without laminar cortical breach, facet joint violation, or collision between both screws.

Results : The success rate of unilateral screw placement was highest at C7 (91.4%), followed by C6 (31.9%), C3 (30.2%), C4 (6.3%), and C5 (4.0%). It was significantly higher in men than in women at C6 and C7 ($p < .001$, respectively). The success rate of bilateral screw placement was also highest at C7 (68.8%), followed by C3 (13.5%), C6 (8.8%), C4 (1.9%), and C5 (0.9%). It was significantly higher in men (83.5%) than in women (52.0%) at C7 ($p < .001$).

Conclusions : To our knowledge, the current study is the largest series to analyze the feasibility of uni- and bilateral subaxial cervical laminar screws. We found a relatively high success rate at C7, particularly with unilateral placement (91.4%), suggesting that laminar screw placement can be a satisfactory alternative fixation method at this level. However, for bilateral laminar fixation at C7, careful patient selection with preoperative evaluation of a CT scan is recommended, particularly for women, who have significantly lower success rates (52.0%) than men (83.5%). Given that the C7 lateral mass is thin, a laminar screw may be an easy alternative to C7 pedicle fixation. This is especially true when only the C6-7 level is being instrumented, since C6 lateral mass screws often cannot be placed next to a C7 pedicle screw. At C6 and C3, screws are only possible in 30% unilaterally and 10% bilaterally. At C4 and C5, laminar screws are rarely (<10%) possible.

* This work is published in Spine J. 2012 Jul;12(7):577-84.

Key Words: Laminar screw, Translaminar screw, Cervical spine, Feasibility, Screw trajectory

Student number: 2008-21903

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INTRODUCTION

In the subaxial cervical spine, pedicle screws and lateral mass screws are commonly used for segmental fixation [1-9]. While pedicle screw fixation provides excellent biomechanical stability [1-3], it is technically difficult, carries the potential for neurovascular injuries and necessitates fluoroscopic or navigational assistance [9-12]. Lateral mass screws are easier and safer, and do not require fluoroscopic or navigational guidance [4,5]. On the other hand, they are biomechanically inferior, particularly at C7, where the lateral mass is small and thin [6-8]. Neither pedicle nor lateral mass screws may be possible in certain rare situations such as with thin pedicles, anomalies of the vertebral artery, or bone defects. In addition, in case of screw cut-out, loosening or errant positioning, a salvage fixation technique is required. Furthermore, additional fixation to augment these screws may be needed in some situations where stronger fixation is needed.

Use of laminar screws in the cervical spine was first introduced by Wright, who reported a cross laminar fixation technique for C2 [13]. This technique has several advantages. Screws can be placed under direct vision and palpation, which obviates the need for fluoroscopic or navigational guidance. Furthermore, it is associated with a relatively low risk of critical neurovascular injury, particularly of the vertebral artery [13]. For these reasons, C2 laminar screws have rapidly become popular [14-17], and recently, several studies have described the usage of laminar screws in the subaxial cervical spine (C3-C7) [18-22]. Particularly for C7, satisfactory biomechanical properties such as pull-out strength, motion resistance [18, 19] and satisfactory clinical results and fusion rates have been reported [20]. Hong et al. [21] reported the results of 11 patients in whom 34 laminar screws were successfully used at C3-C7. This is representative of the few studies regarding subaxial cervical laminar screws [18, 21-23], in that only small numbers of cases were included and discordant results were demonstrated. Therefore, the purpose of this study was to specifically evaluate the anatomical feasibility of laminar screw placement in the subaxial cervical spine using a large number of computerized tomography (CT) scans and 3-dimensional screw insertion simulation software. Of note, laminar screw placement in the subaxial cervical spine is not approved by the U.S. Food and Drug Administration.

MATERIALS AND METHODS

Inclusion and exclusion criteria

This study was approved by our institutional review board. Cervical spine CT scan (Mx8000 IDT; Philips Medical Systems, Best, the Netherlands) images taken in 1.0-mm slices between January 2009 and December 2009 at a single institution were initially included for analysis. Patients meeting the following criteria were excluded: (1) patients under 20 years of age, (2) postoperative patients in whom normal anatomic structures were destroyed, (3) those with unsatisfactory image quality or with metal artifact, (4) those having congenital cervical vertebral anomalies such as hemivertebrae, and (5) those with infection, tumor or fractures.

Computer simulation

Digital images of axial CT scans were analyzed using 3-dimensional screw trajectory software (Vworks, Cybermed, Inc., Reston, VA), which had a simulation function similar to preoperative planning software used for intraoperative computer-assisted navigation systems. After 3-dimensional reconstruction and clipping of unnecessary anatomical structures, laminar screw placement was simulated (Figs. 1-3). Screw entry points and trajectories were determined simultaneously referring to both multi-planar images and 3-dimensional images. During all these procedures, the orthogonal axial, sagittal and coronal CT scan images (Fig. 1), as well as the 2-dimensional images in the plane along the axis of the screw trajectory (Figs. 2 and 3) were evaluated together with the 3-dimensional images.

Screw trajectories

Screw placement was simulated using techniques similar to the ones described by Wright for C2 laminar screw placement [13]. The entry point was placed at the junction of the spinous process and lamina (Fig. 1). The screw was inserted parallel to the slope of the contralateral lamina to avoid cortical breach, particularly of the ventral lamina. For bilateral fixation, the entry points of 2 screws had to be adjusted craniocaudally to allow both to be inserted (Figs. 2 and 3). The entry point of the caudal screw was placed close to the caudal margin of the lamina at the spino-laminar junction. Its trajectory was kept approximately parallel to the inclination of the caudal margin of the opposite lamina. The contralateral screw was inserted at a point located more cranially and the direction was kept slightly caudad in order to place it into the thicker portion of the lamina. During simulation, the entry points and trajectories of both screws were adjusted in order to avoid collision, as well as a breach of the laminar cortex. Screw collision can be minimized if the entry point of the cranial screw is moved more cranially and that of the caudal screw more caudally. However, if the entry points are located too far away from the mid-point, cortical breach can occur more frequently, because the lamina is the thickest at the mid-point in the cranial-caudal direction [16, 23]. Because of the trade-off between screw collision and cortical violation, we adjusted the entry points and trajectories several times to find the optimal entry points and trajectories in each patient.

Screw dimension

For fixation in the subaxial spine, 3.5-mm screws are commonly used. Allowing 0.5-mm space for safety margin around the screw and bone loss by decortication following screw placement in real surgery, 4.0-mm screws were used in our simulation. Screw length was set to 24 mm, since 24-mm length screws were used in previous biomechanical and anatomical studies on laminar screw fixation at C7 [18, 19].

Evaluation of the feasibility

We first evaluated the feasibility of unilateral laminar screw placement on each side. If unilateral screw placement was feasible on both sides of a given lamina, the feasibility of bilateral fixation without screw collision, which requires a larger bony space, was evaluated.

We defined “laminar cortical breach” as violation of the outer laminar cortex by the screw (Figs. 2 and 3). A 24-mm long screw can violate the facet joint if the lamina is not long enough. Therefore, unilateral screw placement was defined to be successful when a screw could be placed without facet joint violation, as well as without cortical violation (Figs. 2 and 3). Bilateral screw placement was defined to be successful when both screws could be placed without collision as well as without laminar cortical breach and facet joint violation (Figs. 2 and 3).

Success rates of unilateral and bilateral laminar screw placement were evaluated at each level. Each level was compared to all of the other levels. We also compared the right versus the left sides, as well as men versus women. For each case with failed screw placement, causes of failure were analyzed.

Statistical analyses

Chi-square test was used for comparison of the success rates between men and women. McNemar test was used to compare the success rates of unilateral screw placement between the right and left sides. The success rates were compared among 5 levels using Cochrane Q test and post-hoc multiple McNemar tests with Bonferroni correction. The SPSS software package, version 17 (SPSS, Chicago, Illinois) was used and the level of significance was set at $p<.05$ for all statistical analyses.

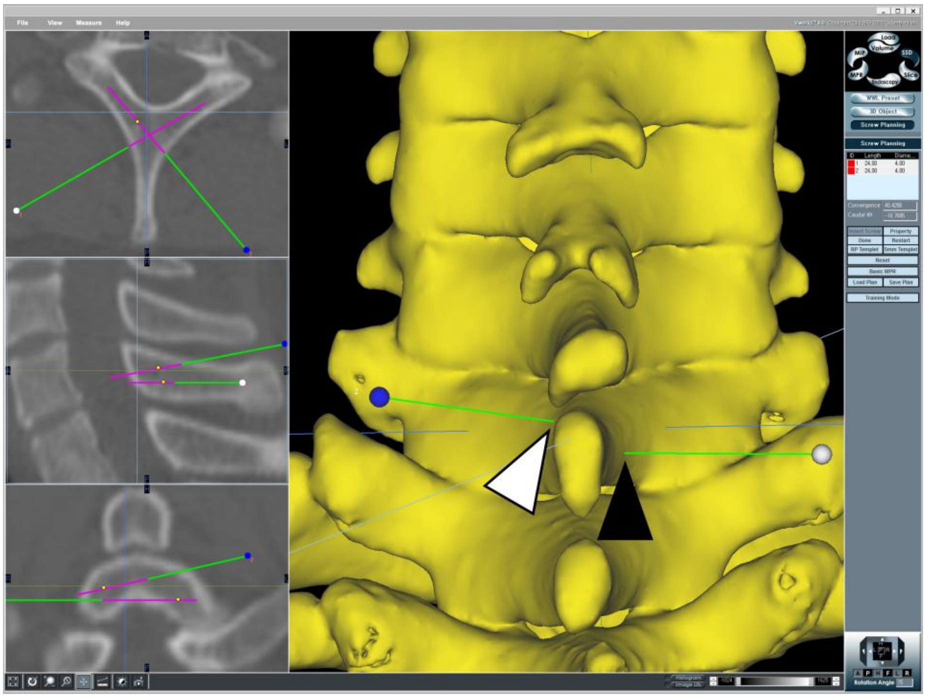

FIGURE 1: The entry points and the screw trajectories are shown. The caudal screw enters at the spino-laminar junction close to the caudal margin of the lamina (black arrowhead). The contralateral screw enters a point located more cranial to avoid collision with the caudal screw (white arrowhead). Both screws are directed parallel to the slope of the contralateral lamina to minimize cortical breach while avoiding the other screw.

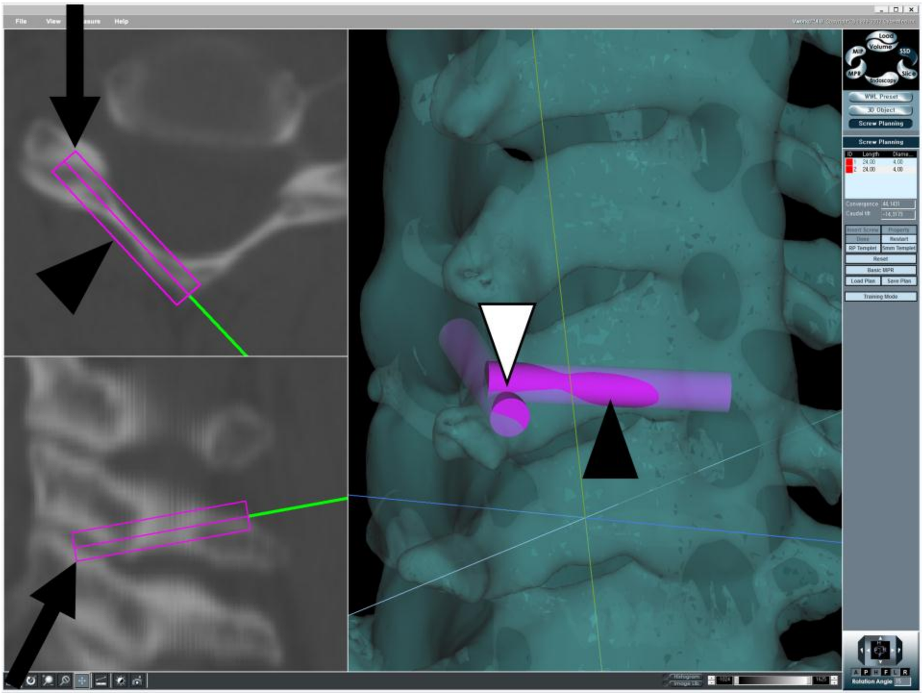

FIGURE 2: Three causes of failed screw placement are shown: laminar cortical breach (black arrowheads), facet joint violation (black arrows), and collision with the other screw (white arrowhead).

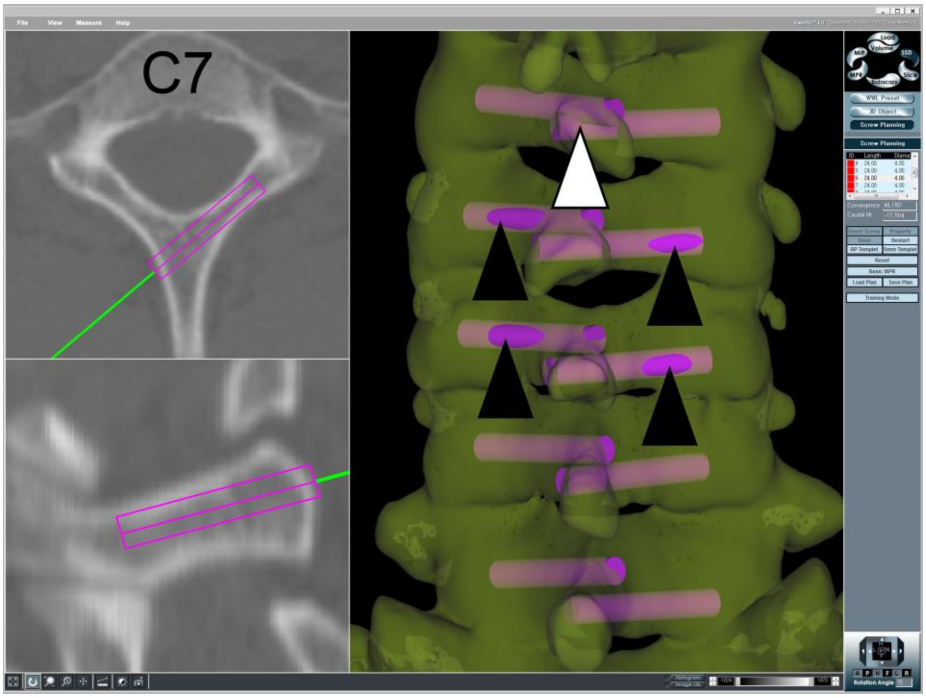

FIGURE 3: An image of simulated bilateral laminar fixation from C3 to C7 is shown. The screws are successfully placed at C6 and C7. The screws at C4 and C5 breached the laminar cortices (black arrowheads). The screws at C3 were placed without laminar cortical breach but with collision between the two (white arrowhead).

RESULTS

Demographic data

Two-hundred-fifteen consecutive patients fulfilling the selection criteria were included in this study, for 430 screws at each of the 5 levels from C3 to C7. Therefore, there were a total of 2150 (430x5) screw simulations. There were 115 men and 100 women. The average age of the patients was 57.9 years (range, 20 to 87 years).

Success rate of screw placement

Table 1 summarizes the success rate of unilateral screw placement. It was the highest at C7 (91.4%, 393/430), followed by C6 (31.9%), C3 (30.2%), C4 (6.3%), and C5 (4.0%). It was significantly higher at C7 than at C6 and C3 ($p < .001$), while C6 and C3 were not significantly different. It was significantly higher at C6 and C3 than at C4 and C5 ($p < .001$), while C4 and C5 were not significantly different. The success rate was significantly higher ($p < .001$, respectively) in men than in women at C7 (men, 96.5%; women 85.5%) and C6 (men, 41.7%; women, 20.5%), but not significantly different at other levels (Fig. 4). There was no statistically significant difference between the right and left screws at all levels.

As shown in Table 2, the success rate of bilateral screw placement was the highest at C7 (68.8%, 148/215), followed by C3 (13.5%), C6 (8.8%), C4 (1.9%), and C5 (0.9%). It was significantly higher at C7 than at C3 and C6 ($p < .001$), while C3 and C6 were not significantly different. It was significantly higher at C3 and C6 than at C4 and C5 ($p < .001$), while C4 and C5 were not significantly different. The success rate was significantly higher in men (83.5%) than in women (52.0%) at C7 ($p < .001$), but not significantly different at the other levels (Fig. 5).

Three causes of failed screw placement

As described above, there were 3 causes of failed screw placement: laminar cortical breach, facet joint violation, and collision between 2 screws (Figs. 2 and 3). Table 3 summarizes the frequency of the causes of failed bilateral fixation. At C3, C4, C5 and C6, the most common cause of failure was laminar cortical breach resulting from small laminar width. At C7, collision between screws was the most common cause of failure. Facet joint violation occurred in a small number of patients and was always accompanied by laminar cortical breach.

Table 1. The success rate of the unilateral screw placement

		C7[*]		C6[*]		C3[*]		C4[*]		C5[*]
Total	Right (n=215)	196 (91.2%)		69 (32.1%)		63 (29.3%)		11 (5.1%)		8 (3.7%)
	Left (n=215)	197 (91.6%)		68 (31.6%)		67 (31.2%)		16 (7.4%)		9 (4.2%)
	Both (n=430)	393 (91.4%)		137 (31.9%)		130 (30.2%)		27 (6.3%)		17 (4.0%)
	p[†]		<.001		.592		<.001		.098	
Men	Right (n=115)	112 (97.4%)		49 (42.6%)		38 (33.0%)		6 (5.2%)		6 (5.2%)
	Left (n=115)	110 (95.7%)		47 (40.9%)		40 (34.8%)		7 (6.1%)		7 (6.1%)
	Both (n=230)	222 (96.5%)		96 (41.7%)		78 (33.9%)		13 (5.7%)		13 (5.7%)
	p[†]		<.001		.059		<.001		1.00	
Women	Right (n=100)	84 (84.0%)		20 (20.0%)		25 (25.0%)		5 (5.0%)		2 (2.0%)
	Left (n=100)	87 (87.0%)		21 (21.0%)		27 (27.0%)		9 (9.0%)		2 (2.0%)
	Both (n=200)	171 (85.5%)		41 (20.5%)		52 (26.0%)		14 (7.0%)		4 (2.0%)
	p[†]		<.001		.126		<.001		.012	
p[‡]		<.001		<.001		.053		.566		.075

[*] The first row is sorted by the order of success rate (C7-C6-C3-C4-C5).

[†] *Post-hoc* multiple McNemar tests with Bonferroni correction was used for comparisons between levels.

[‡] Chi-square test was used for comparison between men and women.

Table 2. The success rate of the bilateral screw placement

	C7*		C3*		C6*		C4*		C5*
Total (n=215)	148 (68.8%)		29 (13.5%)		19 (8.8%)		4 (1.9%)		2 (0.9%)
p†		<.001		.121		<.001		.625	
Men (n=115)	96 (83.5%)		17 (14.8%)		14 (12.2%)		3 (2.6%)		1 (0.9%)
p†		<.001		.663		.007		.625	
Women (n=100)	52 (52.0%)		12 (12.0%)		5 (5.0%)		1 (1.0%)		1 (1.0%)
p†		<.001		.092		.125		1.00	
p‡	<.001		.551		.065		.625		1.00

* The first row is sorted by the order of success rate (C7-C3-C6-C4-C5), which is different from Table 1.

† *Post-hoc* multiple McNemar tests with Bonferroni correction was used for comparisons between levels.

‡ Chi-square test was used for comparison between men and women.

Table 3. Three causes of failed bilateral screw placement

Causes of failure	C7*	C3*	C6*	C4*	C5*
Laminar cortical breach	30 (14.0%)	161 (74.9%)	162 (75.3%)	206 (95.8%)	210 (97.7%)
Facet joint violation	0 (0.0%)	3 (1.4%)	2 (0.9%)	6 (2.8%)	7 (3.3%)
Collision between 2 screws†	37 (17.2%)	25 (11.6%)	34 (15.8%)	5 (2.3%)	3 (1.4%)

* The first row is sorted by the order of success rate (C7-C3-C6-C4-C5), as in Table 2.

† Collision between 2 screws was verified only when screws could successfully be placed bilaterally without laminar cortical breach and facet joint violation.

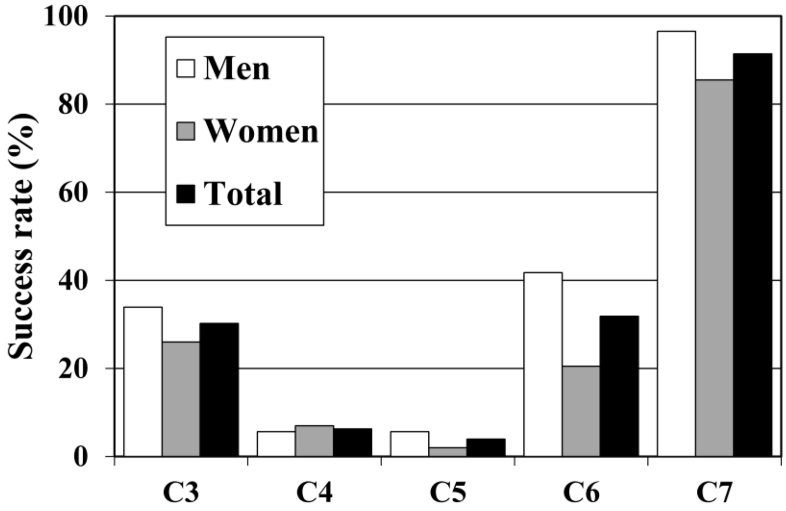

FIGURE 4: The success rates of unilateral screw placement are shown.

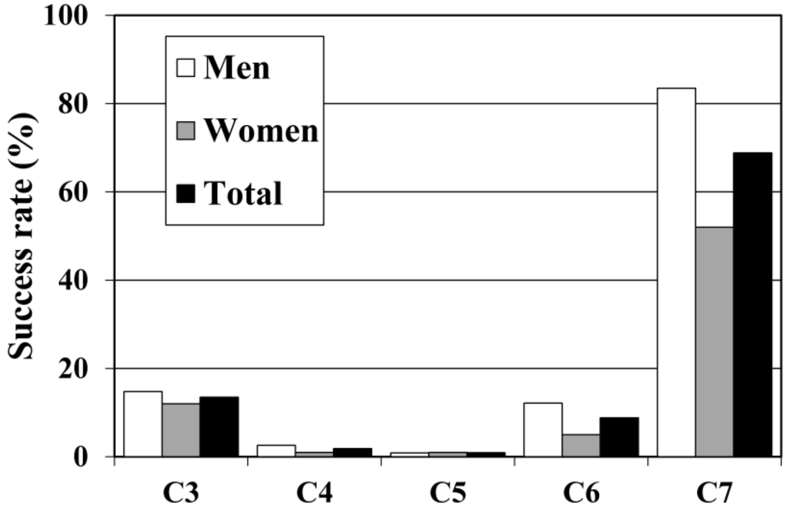

FIGURE 5: The success rates of bilateral screw placement are shown.

DISCUSSION

As C2 laminar screws have become more popular, surgeons have tried to expand the usage of laminar screws to the subaxial cervical spine [18-22]. In order to provide practical guidelines for usage of subaxial laminar screws, it is important to determine the percentage of cases in which these screws are feasible. We could find only 3 reports related to the feasibility of subaxial cervical laminar screws in a computerized search utilizing MEDLINE [18, 22, 23]. Although each of these studies provides valuable information regarding the feasibility of this technique, they also have limitations, as follows. Xu et al. [23], in their measurement study of laminar dimensions from C2 to L5 in 37 cadaver spines, reported that the average thickness in the middle portion was 4.5 mm at C7, and less than 3.0 mm at C3-C6. They did not specifically evaluate the frequency of the vertebrae having adequate dimensions for a given size of laminar screw at each level, as they were not focusing on the feasibility of laminar screw placement in a specific area. Cardoso et al. [18] reported that they were able to place nine 3.5-mm C7 laminar screws without difficulty. This was a biomechanical study so there was no evaluation of the laminar dimensions in a sufficient number of specimens. In addition, they did not evaluate the feasibility at C3 to C6. Nakanishi et al. [22], using CT scans of 42 patients and intraoperative navigation software, reported that the anatomical feasibility varied from 0% to 39% for 3 mm screws and from 0% to 13% for 4 mm screws according to the spine level (C3-C7) and gender. Although they analyzed the feasibility with more advanced methods, they used inner cortical margin instead of the outer cortical margin as the criterion of the successful screw placement. This criterion seems to be too strict and resulted in a very low success rate. Importantly, none of the above studies have evaluated the feasibility of bilateral fixation, which requires larger laminar dimensions than unilateral screw fixation and thus has a lower success rate. In addition, only a small number of cases were evaluated. Given the limitations of the previous studies, we specifically evaluated the anatomical feasibility of subaxial cervical laminar screw placement using a large number of CT scans and 3-dimensional screw trajectory software.

Findings and interpretation of the current study

Our study demonstrates that the feasibility of the laminar screw is dependent on the cervical spine level. The success rate of unilateral laminar screw placement was the highest at C7 (91.4%). The high success rate at this level suggests that surgeons may be able to use unilateral C7 laminar screws as an alternative or salvage fixation technique. Although the success rate in women (85.5%) was significantly ($p < .001$) lower than men (96.5%), it was still reasonably high. At C6 and C3, approximately 30% (31.9% and 30.2%, respectively) of cases demonstrated successful screw placement. Therefore, at these levels unilateral laminar screw placement can be considered in carefully selected patients. For this, preoperative evaluation using CT scans are recommended. In contrast, at C4 and C5 the success rate was just 6.3% and 4.0%, respectively. Therefore, laminar screw insertion is not recommended at these levels for the vast majority of cases.

The success rate of bilateral laminar fixation was the highest at C7, as it was for unilateral screw placement. Although the success rate was not as high as for unilateral placement (91.4%), bilateral fixation at C7 was feasible in approximately two-thirds of the patients (68.8%). However, it should be noted that the success rate was significantly lower in women (52.0%) than in men (83.5%). Preoperative evaluation of the CT scan and careful patient selection is recommended, particularly for women, when bilateral C7 laminar fixation is planned. At the other subaxial levels, the success rate ranges from 0.9% to 13.5%, and therefore bilateral laminar fixation is generally not recommendable.

Comparison with previous studies

Among the 3 previous studies which have examined the feasibility of subaxial cervical laminar screw placement [18, 22, 23], only the one by Nakanishi et al. [22] specifically analyzed the anatomical feasibility using a relatively large number of cases. In an analysis of CT scans of 42 patients their success rate was only 0% to 39% for 3 mm screws and 0% to 13% for 4 mm screws. Even at C7, where the success rate was the highest, 4 mm screws had 13% success rate for men and 3% for women. This is much lower than the results of the present study as well as the other 2 previous studies. Xu et al. [23] reported that the average thickness of the C7 lamina in the mid-portion was 4.5 mm. This suggests that the success rate would be much higher than the results of Nakanishi et al. [22]. Cardoso et al. [18] reported that all 9 C7 vertebrae were large enough to accommodate a 3.5-mm laminar screw. The major reason for the difference between the results of Nakanishi et al. [22] and the current study may be explained by the difference in the criterion for the successful insertion. They used violation of the inner cortical margin as the criterion, while we defined violation of the outer cortical wall as the failure of screw insertion. We believe that laminar screws do not need to remain only in the marrow cavity to be considered successful; so long as there is no breech of the spinal canal, the screw is safe.

Screw dimension and clearance around the screws

The width of lamina assumed to be necessary for the safe laminar screw placement in the cervical spine varies from 3.0 mm to 5.5 mm [16, 22, 24-27]. We used 0.5 mm clearance around a 3.5-mm screw, and as a result, simulated using a 4.0-mm screw. This allows 0.5 mm of leeway, if a standard 3.5 mm screw is utilized. Had we used 1mm of leeway, there would be an underestimation of the feasibility and may not reflect the live surgical settings where the screws can be placed relatively easily under direct visualization with tactile feedback. Considering these, we think 0.5 mm is reasonable assumption for the clearance.

Limitations of this study

As with any study, there are a number of limitations with ours. First of all, the current study is based on computer simulation rather than using real cadavers. Computer simulation is not as realistic as a cadaver study. However, it enables changing trajectories without breaking the specimen, testing the feasibility of both unilateral and bilateral screw placement with a different trajectory for each, and testing a large number of patients. Second, we simulated placement of a screw having 24-mm length and 3.5-mm diameter with additional 0.5-mm clearance for the reasons mentioned above. Screw dimensions and the amount of clearance would definitely influence the success rate. Third, locating the entry points during an actual operation is likely to be more difficult than with a computer-simulation. We could change the entry points and insertion angles several times before determining the trajectory for each case. Since this is not possible during real operations, the current study probably overestimates the success rate. On the other hand, it should be remembered that small amounts of laminar cortical breach in real surgery would not cause a problem in most cases. Finally, race, age, height, weight and the original diagnosis of our subjects were not considered in this study.

Despite these limitations, we believe that this study has unique strengths. We specifically evaluated the feasibility of subaxial laminar screw placement using, to our knowledge, the largest number of specimens in the English-language literature. The feasibility was assessed using 3-dimensional simulation, which can verify the presence or absence of laminar cortical breach and facet joint violation more exactly than measurement on simple 2-dimensional images. We analyzed the feasibility of bilateral laminar fixation, as well as of unilateral screw placement.

Conclusions

To our knowledge, the current study is the largest series to analyze the feasibility of subaxial cervical laminar screw placement and the first to evaluate the feasibility of bilateral fixation. We found a relatively high success rate at C7, particularly with unilateral placement (91.4%), suggesting that laminar screw placement can be a satisfactory alternative fixation method at this level. However, for bilateral laminar fixation at C7, careful patient selection with preoperative evaluation of a CT scan is recommended, particularly for women, who have significantly lower success rates (52.0%) than men (83.5%). At C6 and C3, unilateral screw placement has approximately 30% of success and thus can be considered in a limited number of patients, while bilateral fixation is not recommended, since its success rate is approximately 10%. At C4 and C5, laminar screws have such low success rates (less than 10%) that they are not recommended.

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국문 초록

목 적: 경추 나사 고정술 중 후궁 나사 고정술은 여러 장점을 가지고 있다. 투시 영상 장치 및 navigational system등의 부가장치 없이 직접 삽입할 수 있으며, 척추 동맥 등 중요한 혈관 및 신경 손상 위험성이 낮다. 생역학적 강도 또한 외측괴 나사보다는 우월하며, 척추경 나사와 비슷하다고 보고되었다. 하지만, 후궁 나사 삽입의 해부학적 실행 가능성에 대해서는 아직 정확하게 평가되지 않았으며, 이에 본 연구에서는 3차원 컴퓨터 단층 촬영 및 simulation software를 이용하여 경추 후궁 나사 삽입의 해부학적 실행 가능성을 평가하고자 한다.

대상 및 방법: 215례의 컴퓨터 단층 촬영을 이용하여, 각 분절당 430개의 경추 후궁 나사 삽입을 시뮬레이션 하였다. 나사 삽입점과 궤도는 3차원 나사 삽입 simulation software를 사용하여 분석하였으며, 3.5mm 나사를 사용 편측 및 양측 나사 삽입 가능성을 각 경추 분절에 대해 평가하였다. 성공적인 나사 삽입은 후궁 피질골의 파괴, 후관절의 침범 및 양측 나사 사이의 충돌이 발생하지 않는 경우로 정의하였다.

결 과: 편측 후궁 나사 삽입의 성공율은 C7에서 91.4%로 가장 높았으며, C6 (31.9%), C3 (30.2%), C4 (6.3%), C5 (4.0%) 순으로 성공율이 감소하였다. C6,

C7 분절에서는 남성의 후궁 나사 삽입이 여성보다 높은 성공율을 보였다 (p <.001). 양측 후궁 나사 삽입의 경우 역시 C7에서 68.8%로 가장 높았으며, 이후 C3 (13.5%), C6 (8.8%), C4 (1.9%), C5(0.9%) 순서의 성공율을 보였다. 남성에서의 성공율이 여성보다 유의하게 높은 분절은 C7 이였다 (p <.001).

결 론: 이번 연구는 현재까지 알려진 연구 중 편측 및 양측 경추 후궁 나사의 해부학적 삽입 가능성을 평가한 가장 대규모의 연구이다. 편측 후궁 나사 삽입은 C7 분절에서 비교적 높은 성공율 (91.4%)를 보여, 만족스러운 경추 나사 삽입술로 사용될 수 있을 것으로 생각된다. 하지만, 양측 나사 삽입의 경우, 컴퓨터 단층 촬영을 통한 치밀한 술전 계획과 적절한 환자 선택이 필요하다고 생각되며 특히 남성(83.5%)보다 낮은 성공율을 보인 여성(52.0%)에서 주의가 필요하다고 생각된다. C6 분절 및 C3 분절에서는 편측 나사는 30%, 양측 나사 삽입은 10%의 성공율을 보였다. C4 분절과 C5 분절에서는 후궁 나사 삽입이 거의 불가능하다고 생각된다. (<10%)

* 본 내용은 Spine J. 2012 Jul;12(7):577-84에 출판 완료된 내용임

색인 단어: 후궁 나사, 경추 나사, 경추, 시뮬레이션

학 번: 2008-21903