The Feasibility of Multiple Fixation Points in C2

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Study Design: Analysis using three-dimensional simulation software for spinal screw placement and computed tomographic scan images.

Purpose: To assess the feasibility of achieving multiple (three or four) screw fixation points in C2 vertebra by using a combination of pedicle and laminar screws.

Overview of Literature: Secure C2 fixation using multiple screws is required or beneficial in some unique cases. However, to the best of our knowledge, there have been no reports analyzing the feasibility of multiple screw fixation in C2.

Methods: We used 1.0-mm interval computed tomographic scan images of 100 patients (50 men and 50 women) and screw trajectory simulation software. The diameter of all screws was set at 3.5 mm, considering its common usage in real surgery. The anatomical feasibility of placing both pedicle and laminar screws on the same side was evaluated. For all feasible sides, the three-dimensional distance between the screw entry points was measured.

Results: In 85% of cases, both pedicle and laminar screws could be placed on both sides, allowing for the insertion of 4 screws. In 11% of cases, 2 screws could be placed on one side, while only 1 screw was feasible on the other side, resulting in the placement of 3 screws. In all 181 sides where both types of screws could be inserted, the distance between their entry points exceeded 16.1 mm, which was sufficient to prevent the collision between the screw heads.

Conclusions: C2 vertebra can accommodate three (11%) or four (85%) screws in 96% of cases.

Keywords: C2, Pedicle screw, Laminar screw, Multiple screw fixation

Introduction

C2 segmental screws can be placed in the pedicle, pars, or lamina. In most cases, two pedicle or laminar screws can provide sufficient C2 fixation. However, multiple screw placement in C2, meaning placement of three or four screws in C2, may be considered or required in several situations, as follows. First, it may be considered in some
cases during occipito-cervical fixation and fusion (Fig. 1). Occipito-cervical fixation and fusion, using an occipital plate and cervical screws, may need to be extended to the subaxial spine to enhance the stability of the construct. This extension is particularly required in selected cases, such as patients with severe osteoporosis, complex revisions with loosening of previously placed screws, bone defects or screw cut-out resulting in weak anchor points, small bone dimensions that cannot accommodate adequately sized C2 pedicle screws, anterior column defects, and so on. However, the number of fusion levels should be minimized whenever possible. Additionally, extending the fusion caudally below C2 would necessitate detaching the major neck extensor muscles from the C2 spinous process, which could potentially lead to increased neck pain, kyphosis, and limited motion [1]. Therefore, ideally, occipito-cervical fusion should be limited to C2 and above. This can be achieved by reinforcing fixation with multiple (three or four) screw fixation in C2. Secondly, the placement of three or four screws in C2 may prove beneficial even during C1-C2 fusion (Fig. 2) in specific cases such as severe osteoporosis or revision cases where previously inserted C2 screws have become loose. This is particularly relevant when C2 pedicle screws are not feasible. Thirdly, a long fusion extending from C2 or above to a level far below C2 may necessitate additional fixation (Fig. 3) to ensure adequate stabilization in cases involving osteoporosis, cerebral palsy, or complex reconstructive or revision surgery. A possible option for augmentation of stabilization in these situations is the placement of laminar screws at C2 [2] and C7 [3] and/or upper thoracic levels [4], along with interconnection between them. This approach also requires multiple screw fixation in C2.

In these unique situations, we have been placing multiple (three or four) screws in C2 for several hundred cases since 2007. We have presented our principles and cases at many international and domestic conferences, as well as instructional course lectures. In the meantime,
several case reports on placing multiple screws for C2 fixation have been published [5-9]. However, to the best of our knowledge, there have been no reports analyzing the feasibility of multiple screw fixation in C2. Therefore, the purpose of this study was to investigate the anatomical feasibility of achieving multiple fixation points in C2 by using a combination of pedicle and laminar screws.

**Materials and Methods**

1. **Selection criteria**

This study was approved by our institutional review board (B-1303/194-105). One-millimeter interval CT scans of the cervical spine, taken in a single institution (Mx8000 IDT 16; Philips Medical System, Best, The Netherlands) from June 2009 to February 2013, were initially included in this study for analysis. Exclusion criteria were: (1) CT scans of patients under the age of 20 years, (2) those with unsatisfactory imaging of C2 such as those with severe metal artifact by dental implants, (3) congenital anomalies, infection, tumors, and fractures involving C2, and (4) postoperative CT scans. Among those fulfilling the selection criteria, equal number of consecutive patients were selected for each gender.

2. **Computer simulation and screw trajectories**

The analyses were performed using computer simulation with three-dimensional screw trajectory simulation software (Vworks; Cybermed Inc., Reston, VA, USA). This software allowed the reconstruction of a three-dimensional model, along with coronal and sagittal images, from axial CT scan images of the cervical spine taken at 1.0-mm intervals. Screw insertion was simulated simultaneously using those images as reference (Fig. 4). The software facilitated the determination of the entry point, trajectory, diameter, and length for each screw.

The diameter of all screws was set at 3.5 mm, considering its common usage in real surgery. C2 pedicle screws were directed approximately 30° to 40° medially on the axial plane, towards the anterior-superior end of the superior articular process of C2 or just below it, along the superomedial margin of the pedicle [10] (Fig. 4A). The entry point was positioned 3–7 mm caudal to the C1–C2 facet joint and 3–7 mm lateral to the medial border of the pars to accommodate the described trajectory. The entry point for a C2 laminar screw was at the junction of the spinous process and lamina [11] (Fig. 4B). To prevent collision between the two laminar screws, the entry points were adjusted cranially and caudally, respectively. Each laminar screw was aligned along the slope of the contra-
lateral laminar surface, avoiding breaches of either the anterior or posterior cortices of the lamina, as well as collisions between the bilateral laminar screws and between the pedicle and laminar screws.

3. Evaluation of the feasibility

Two types of analyses were conducted. Firstly, the anatomical feasibility of placing both pedicle and laminar screws on the same side was evaluated for each side. “Cortical breach” was defined as any violation of the outer margin of the cortical bone. The anatomical feasibility of the pedicle or lamina to accommodate a 3.5 mm screw without cortical breach was assessed for each screw. “Success” of the screw placement was defined as placement without cortical breach. Secondly, when both pedicle and laminar screws were feasible on the same side, the three-dimensional distance between their entry points was measured to evaluate if the distance is sufficient to allow screw placement without collision between the heads of the ipsilateral pedicle and laminar screws.

Results

1. Patient demographics

CT scans of 100 patients, including 50 consecutive patients for each gender, who fulfilled the selection criteria were analyzed in this study. The mean age was 52±9 years (range, 25–77). We simulated insertion of 200 pedicle and 200 laminar screws.

2. The anatomical feasibility of multiple screw placement in C2

In 85 patients out of the 100 patients, both pedicle and laminar screws were feasible bilaterally permitting insertion of 4 screws at C2 (Table 1). Among the other 15 patients, 11 patients could accommodate both screws on one side and only one screw on the contralateral side at C2 (permitting insertion of a total of 3 screws): 2 pedicle and 1 laminar screws in 4 patients, and 1 pedicle screw and 2 laminar screws in 7. The other 4 patients could accommodate only 1 screw on each side (permitting a total of only 2 screws): 1 pedicle screw on each side in 1 patient, 1 laminar screw on each side in 2 patients, and 1 pedicle screw on 1 side and 1 laminar screw on the contralateral side in 1 patient.

As seen in Table 2, pedicle screws were feasible in 187 sides out of 200, and the upper and lower laminar screws were feasible in 96 and 98 sides out of 100 respectively. On the upper laminar screw side, placement of both laminar and pedicle screws was feasible in 89 patients out of 100 and the mean distance between the entry points of both screws was 19.0±1.6 mm with a minimum of 16.1 mm. On the lower laminar screw side, placement of both laminar and pedicle screws was feasible in 92 patients out of 100 and the mean distance between the entry points of both screws was 21.1±3.0 mm with a minimum of 16.8 mm. Overall, the minimum distance between the entry points of ipsilateral pedicle and laminar screws was 16.1 mm, which was sufficient to prevent the collision between the heads of the ipsilateral pedicle and laminar screws.

Discussion

Strong posterior fixation of C2 can be achieved by bilat-
eral pedicle screw placement in most cases. However, in some cases, bilateral pedicle screws are not feasible, and multiple screw placement is required or beneficial, as described in the Introduction section. The corresponding author has presented his experience of multiple C2 screw placement in many meetings, and we believe this technique is becoming more and more popular. However, we could not find a study analyzing the feasibility of multiple screw fixation at C2. Therefore, we performed this study to analyze the anatomical feasibility of pedicle and laminar screws and the distance between the heads of the two ipsilateral screws to assess the frequency of collision between them.

This study demonstrates that in 85% of cases, both pedicle and laminar screws were feasible bilaterally, allowing for the insertion of 4 screws. In 11% of cases, 2 screws were feasible on one side, and only 1 screw was feasible on the other side, allowing for the insertion of 3 screws. Out of the 200 sides analyzed, 181 sides permitted the placement of both pedicle and laminar screws, with a minimum distance of 16.1 mm between the entry points of the two types of screws. Therefore, the distance was sufficient to prevent the collision between the screw heads in all 181 sides. Consequently, in 96% of cases, the placement of three (11%) or four (85%) screws in C2 was feasible.

As with any other study, this study has several limitations. First, it is based on computer simulation, which is not as realistic as real surgery. As mentioned above, we have been placing multiple screws in C2 for several hundred cases since 2007, and we are planning to report our clinical results of this technique in another paper.

Secondly, we have not analyzed the feasibility of screws and rod assembly. It is mostly determined by screw head mobility and versatility of accessories for connection such as lateral extenders and crosslinks. Fig. 5. shows several examples of screw-rod assembly. Among our clinical experience of several hundreds of cases, we have experienced less than 5 cases where the assembly was not possible. Of note, another issue is bone graft placement through the crowded connecting accessories. We recommend placing bone graft before assembly of the last laminar screw.

Thirdly, we have not analyzed the biomechanical advantages of placing multiple screws in C2. Considering that multiple screw placement is required only in unusual unique situations, we believe that conducting this kind of study with reliable statistical analysis would not be feasible.

Conclusions

Our study aimed to analyze the feasibility of achieving multiple (three or four) screw fixation points in C2 using a combination of pedicle and laminar screws. We found that in 85% of cases, both pedicle and laminar screws could be placed on both sides, allowing for the insertion of 4 screws. In 11% of cases, 2 screws could be placed on one side, while only 1 screw was feasible on the other side, resulting in the placement of 3 screws. Across all 181 sides where both pedicle and laminar screws could be inserted, the distance between the entry points of the two types of screws exceeded 16.1 mm, which was sufficient to prevent the collision between the screw heads. Consequently, in 96% of cases, the placement of three (11%) or four (85%) screws in C2 was feasible.

References