Abstract

The aim of the study was designed to evaluate the biomechanical impact of surgical procedures on the degenerative spine. We hypothesize that degenerative disease may occur at the level adjacent to the level of surgical arthrodesis as a result of the alteration in biomechanical properties.

In the first set of the project, late fusion of anterior plating and posterior wiring stabilization in a 3-column injury model of the cervical spine was done. Eighteen sheep were subjected into sham operations, spinal injury at the C2-3 level plus anterior Caspar plating and posterior wiring stabilization. The results indicated that the anterior plate-stabilized spines were more stable over time than did the posterior-wired spines, while this biomechanical privilege failed to result in larger fusion masses nor did it attenuate an effect of stiffening adjacent functional unit following stabilization. The weakness for opposing rotation load, however, might contribute to the formation of osteophytes in the exclusively posterior wired-spines. These data point out a complex interaction between the biomechanical redistribution and the bone grating maturation, osteophytic formation and restricted adjacent levels’ motion following different implant treatments in the cervical spine.

In the second set of experiments, we have created a model of one-level degenerative cervical spine in sheep. Over 30 sheep have received induced degeneration of C2-3 disc by way of multiple incisions into the disc. Portable X-ray is needed for each animal to verify the degree of degeneration.
Final results

In the second set of experiments, we had created a model of one-level degenerative cervical spine in sheep. Over 30 sheep had received induced degeneration of C2-C3 or C3-C4 disc by way of multiple incisions into the C2-C3 or C3-C4 disc. Portable X-ray had been used for verifying the level of surgical procedure and finally animal degeneration level checkup. The operation animals fed freely and without any neck prosthesis used. After six months holding, we had preceded the procedures of discectomy with and without intervertebral autologous iliac bone grafting in the past one and half years.

However, twenty-five sheep survived and were sacrificed to harvest the cervical spine. Mortality rate was about 16.7%. Two sheep in the intervertebral autologous bone graft group died of surgical site infection in spite of postoperative antibiotics administration. The infected cervical spines were exclusive for the biomechanical test. Biomechanical test in a pure moment model had been performed in our previous work with Selspot II motion analysis system, but we met a big trouble in the following biomechanical experiment and so as to cease the test. Due to Selspot II motion analysis hardware and software broken down, biomechanical test have been postponed till these recent time. After repetitive confirmation tests of other motion analysis as Vicon system, the biomechanical test on degenerative spine model are proceeding now.

Another problem was also encountered in this project and was a big trouble for us. The Barbados black belly sheep were assigned to be involved in this animal model in our previous plan. However, due to their rarity in Taiwan and almost only few sheep left after our previous experiments, limited amount of these sheep were available and not so many sample numbers enough could be involved in the experiment to get significant result.

Although so many troubles were encountered in the past three years, we have got some results during this period. The radiological findings from these specimen showed that the C2-3 and C3-C4 disc space were narrowed and anterior spur formation, kyphotic deformation were also clearly shown in the experimental group of the radiological images. Reactive hyperostosis was also noted in the radiological examination. However, the control group revealed normal lordotic curve with all the disc spaces to be preserved well with compared to the cervical disc injured group. Biomechanical test were planed to do after animal sacrificed, but due to reset up the motion analysis system with Vicon device and continuing calibrating the system, so we will follow the results and keep analysis of the final data set.
Fig. 1 The above figures showed C3-C4 disc space narrowing and reactive hyperostosis over the disc space. Increased degeneration over induced one segment of cervical spine was successfully created in an animal cervical spine model.

Fig. 2 Normal disc space and alignment were found in the control group.
The following document are the result of first set experiment and it has been submitted to the Acta Neurochir (Wien) and pending for the reply.

Abstract

Objective: We evaluated the delayed effect of anterior plating versus posterior wiring on the kinematic response and intervertebral fusion in a complete cervical destabilization model.

Methods: Seventeen sheep were included, and six of which underwent sham operation (Group A, n=6). The other eleven received the C2-C3 destabilization, by removing intervertebral disc, anterior and posterior spinal ligaments, and bilateral facet joints, followed by intervertebral bone grafting and fixation either with anterior plate (group B, n =5) or posterior wiring (group C, n = 6). Six months after surgery, radiographic examinations were taken, and the animals were killed. Ligamentous spines (C1-C5) were subjected to the relevantly applied loads. The load-deformation data of the C2-C3 and C3-C4 functional units were recorded and analyzed.

Results: At the C2-C3 functional unit, Group B had the least motion ranges in flexion, lateral bending, and rotation loads than did the other two groups. Significantly smaller motion ranges of lateral bending and rotation loads were found in Group B than in Group C ($P < 0.05$). Compared to Group A, Group C had a decreased motion range in flexion load but showed increased motion range in rotation load. Consequently, Group C had superior intervertebral fusion and more osteophytes than did Group B. At the C3-C4 functional unit, Group B showed significantly decreased motion ranges in extension and lateral bending loads ($P < 0.05$), while Group C did not.

Conclusion: The results indicated that the anterior plate-stabilized spines were more stable over time than did the posterior-wired spines, while this biomechanical privilege failed to result in larger fusion masses nor did it attenuate an effect of stiffening adjacent functional unit following stabilization. The weakness for opposing rotation load, however, might contribute to the formation of osteophytes in the exclusively posterior wired-spines. These data point out a complex interaction between the biomechanical redistribution and the bone grating maturation, osteophytic formation and restricted adjacent levels’ motion following different implant treatments in the cervical spine.

Key Words: Kinematics, Cervical discectomy, Bone grafting, Anterior plating, Posterior Wiring, Late Fusion.
Introduction

Cervical fusion with bone grafting and complementary implant fixation are now firmly established and widely accepted to treat unstable conditions arising from trauma, a tumor, and destabilizing surgical procedures such as wide laminectomy of the cervical spine [9, 19, 29]. For cervical disc disease, the anterior-plate fixation has also been suggested for those patients at risk to develop soft tissue fusion, although most authors agree that an independent use of bone bulk across the discectomied space is enough for achieving solid bone fusion and maintaining disc height [13, 16, 34].

Treatment modalities for cervical spine stabilization, however, may include either anterior or posterior fixation, or even further both in one session, each of which has gained supporting rationale(s) to be used in the neurosurgical practice. Some authors advocated the use of the anterior-plate fixation, with an intervertebral bone graft intervened at the discectomied site, to achieve immediate stabilization and subsequent bone fusion [5, 12, 14, 31]. Other authors recommended the use of the posterior fixation and structural bone grafting or, even, a combination application of anterior and posterior fixations with bone grafting [1, 4, 17, 28].

Sophisticated knowledge of kinematics and biomechanical data may provide a useful guide in deciding the operative approaches for various cervical spine diseases. It may also be helpful in preventing the potential late complications that can be caused by the biomechanical redistribution after treatment [11, 16, 25]. Using a sheep cervical spine model involving late fusion, we have previously shown that C2-C3 cervical discectomy without bone grafting formed a dense soft tissue response with irregular and noncontinuing bone bridges across the discectomied space that could oppose the lateral bending but not the axial rotation loads [16]. This biomechanical change in rotation load was noted to occur at both the discectomied (C2-C3) and adjacent (C3-C4) functional units in the pure-moment biomechanical testing. Thus, it was possible that C2-C3 anterior discectomy would redistribute the loads applied by the cervical musculature in vivo, which eventually caused a load-specific ligamentous laxity of the C3-C4 functional unit that become apparent in the in vitro testing. This discectomy-relevant hypermotility in rotation, either at the C2-C3 or C3-C4 functional unit, however, much improved following the use of intervertebral bone
grafting.

Interestingly, C2-C3 cervical discectomy was also associated with an increased motion range of the C3-C4 functional unit in flexion load that could not be reversed during a course of intervertebral bony maturation. It has been known that mechanical implant fixation may possess a load-sharing or -shielding biomechanical character and, thus, may have potential to rectify the redistribution of physiological loads over time, either caused by discectomy or the loss of functional discs, onto the cervical musculature [6, 22]. We therefore suppose that perhaps using an implant fixation bridging across the space of discectomy and bone grafting, the excessive physiological flexion load onto the cervical musculature may be much attenuated and these adverse kinematic changes of the adjacent functional unit improved.

In order to extend our original findings and in line with standard treatment modalities for unstable cervical spine disorders, we herein investigate the kinematics of late fusion results following cervical discectomy and intervertebral bone grafting plus an implant fixation in a sheep unstable cervical spine model. We also attempted to determine whether anterior plating could offer superior stability over time and, therefore, resulted in a better kinematic response and fusion quality than did posterior wiring.

**Materials and Methods**

**Animal Preparation**

All procedures followed the guidelines of the National Institutes of Heath (Guide for the Care and Use of Laboratory Animals) and were approved by the University animal ethics committee. Eighteen healthy adult Barbados Black Belly sheep of either gender, aged 1-2 years old and weighing 40 to 45 kg, were used in this experiment. Anesthesia was induced by the intramuscular administration of ketalar (50 mg/kg) and was maintained by α-chloralose (40 mg/kg). The sheep were intubated and mechanically ventilated with a respirator under full muscle paralysis induced by the intravenous administration of pancuronium bromide (8 mg/h).

**Surgical Procedure and Stabilization**

With the animal in the supine position and its head in normal cervical lordosis, standard anterior
cervical approach was first employed. Briefly, a right vertical incision along the anterior border of the sternocleidomastoid muscle was made for exposing the C2 and the C3 vertebrae. The exposure was widened and deepened by blunt and sharp dissections. With the carotid sheath laterally retracted, the deep cervical fascia overlying the longus colli muscles and the anterior longitudinal ligament were incised in the midline and dissected from the vertebral bodies and from the adherent annulus fibrosus of the disc. The levels of exposed vertebrae were verified by a lateral radiograph of cervical spine. C2-3 discectomy was employed through incising the annulus and then removing the nucleus, the remaining cartilaginous end plates as well as the underlying posterior longitudinal ligament. The harvest and the insertion of autologous iliac crest graft (1.4x1x0.7 cm³ in size) were performed according to the Smith-Robinson technique [10, 23].

The animals were then positioned prone with the cranium supported on a head holder. Posterior cervical approach was performed through a midline incision staying exactly into the midline raphe of posterior neck muscle bundles. When approaching the cervical spine, subperiosteal dissections were made to detach the erector spinae muscles away from the posterior elements from C1 to C4. Once the spine was exposed as far laterally as the facet joints, self-retaining retractors were placed and the articular processes between the C2 and the C3 were chiseled out bilaterally. All posterior ligamentous structures between the C2 and the C3 were incised.

Anterior instrumentation was performed with the Caspar anterior trapezoidal plate (37 mm in length, Aesculap, San Francisco, CA) transfixed with 2 bicortical screws (17-18 mm in length) to each vertebral body of the C2 and the C3 [5, 12, 14, 31]. A modified triple-wire technique was used for posterior wiring [2]. Briefly, drill-holes were placed through the base of the spinous processes of the C2 and the C3. Holes were drilled with a small diamond burr, and a towel clip was used to enlarge the holes for multiple passes of wires. A twisted bundle of triple 20-gauge wires was then passed through and around the spinous processes of the C2 and the C3 (including a sublaminar loop of the C3 lamina). The wires were tightened gently to hold the vertebrae in position.
Grouping

The animals were divided into three groups. In each group, six sheep were included. In Group A, each sheep received sham anterior and posterior operations to fully exposing the anterior and posterior vertebral surfaces without disturbing the bony and ligamentous structures. In Group B, animals received C2-C3 cervical discectomy and the removal of anterior and posterior spinal ligaments as well as bilateral facet joints. The insertion of autologous iliac crest graft was immediately employed under moderate retraction of disc space, followed by the fixation with the anterior Caspar plate and screws over the same levels to achieve stabilization. Group C sheep underwent the same procedure of C2-C3 destabilization and was re-stabilized by the insertion of autologous iliac crest grafting and posterior wiring. Intraoperative and postoperative antibiotics were administered intravenously. After 24 hours of intensive observation, the animals were allowed activity and were fed a regular diet. Neurological examinations were performed weekly along with monitoring of the animal’s eating habits, ambulatory activities, and wound healing. No attempt was made to immobilize the animals’ neck. Repeated radiographs were required during the initial 3 postoperative months to ensure that the implant did not extrude. Preliminary data indicated that, without complementary implant stabilization, animals subjected to C2-3 destabilization rapidly developed quadriplegia and could not survive for more than one week after the surgery, even with the presence of intervertebral grafting.

Sacrifice and Specimen Preparation

Six months after surgery, a lateral radiograph was again obtained to evaluate the structural integrity of the operative level. The animals were then killed, using the injection of overdose pentobarbital, so that the cervical spine specimens (C1-C5) could be obtained. Each specimen was sealed in double plastic bags and kept in frozen at -60°C until further preparation for testing.

Each specimen was cleaned of ligament nuchae and all muscle tissue while taking care to preserve the other ligamentous structures. The end vertebrae (C1 and C5) were transfixed with perpendicular pins to
enhance fixation with mounting jigs. For eliminating the rotation between C1 and C2, one thread rod (0.25 x 1.5 in) was used to transfix the anterior arch of the C1 to the odontoid process. The specimen was oriented in a physiological position, with the C3-4 disc space horizontally placed. The prepared specimen was attached to the base of a testing cage.

**Biomechanical Testing**

A set of three infrared light-emitting diodes (LEDs) was rigidly attached to each vertebra of C2-C4 as the definable points for three-dimensional motion. Two LEDs were screwed at the ends of Steimann pin (0.25 x 1.5 in) drilled through the spinous process and the third LED was fixed at the inferior midportion of each vertebral body. Another set of three LEDs was attached to the base for defining an anatomically relevant Cartesian axes system. Thus, a total of 12 LEDs was used for each test. A Selspot II system (Selcom Selective Electronic, Inc., Valdese, NC) was used for motion monitoring [16, 24, 26, 27, 32]. The LEDs were fired sequentially, and the emitted light was picked up by four cameras, in terms of X, Y, and Z voltages, through infrared light detectors, analog amplifiers and associated calibration.

Experimental moment exerted on the specimen was by a loading system, as described previously [16]. Briefly, the base of loading frame would allow sliding toward the movement direction of the tested specimens. With two sets of parallel loads applying simultaneously onto two slides, each of which was attached laterally to one side of the loading frame, a couple was obtained, which enable one to approximate pure moments as closely as possible. The loading frame was preloaded with 5 N. By gradual additions of 100- to 300-g weights, a final moment of 0.72 Nm was achieved. Load steps were repeated five times in a prescribed load type sequence, and the weight increments were added in 30-second time intervals. The fifth cycle LED locations relative to each load type were recorded and analyzed in the study.

The spatial locations of LEDs were defined with relevance to the anatomically Cartesian axes system located at the base plate. The spatial data were compiled and then transformed into three Bryant/Euler angles as the relative rotations between any two contiguous vertebrae. These angles represented three primary vertebral rotations: rotation in the sagittal plane for flexion and extension, rotation in the transverse...
plane for axial rotation, and rotation in the frontal plane for lateral bending.

**Quantification of Bony Fusion**

Bony union was defined as a solid consolidation if the interface showed continuous bone density and had clearly crossing bone trabeculae. To determine the quality of intervertebral fusion and the coupling resorption of bone grafting, a semi-automated computerized imaging analysis system (MCID, Imaging Research Inc., Ontario, Canada) was used to measure the integrated optical density concentration (IOD(c)=sum of pixel concentration values/numbers of pixels) and the dimension (mm²) of the discectomied space. To avoid a light source-induced error and to compensate for the variations in radiographic exposure as well as tissue mineralized density from animal to animal, the formal data were further expressed as a ratio relative to the density concentration of the C1 [30]. The dimension data were expressed as a percentage of the mean value of the sham-operated group. In addition, posterior extension of bone margin (mm) was measured with adjustments for magnification of lateral radiographs.

All data presented in this study are expressed as mean ± standard error of the mean (SEM). Differences among groups were analyzed using the Kruskal-Wallis test at each variable. The Mann-Whitney U test was conducted when indicated. A p value of less than 0.05 was selected for statistical significance.

**Results**

Mortality was 5.6%. One Group B animal had implant extrusion during the early postoperative period, obviously as a consequence of technical failure. The animal eventually developed quadriplegia and died before completing the recovery protocol, and was, therefore, not included in the 17 animals used for data analysis. The other animals with either the anterior-plate or the posterior-wire stabilization did not have observable implant extrusion or fixation loosening during the whole observation period.

All the animals receiving implant stabilization showed various degrees of bony fusion, but there was no spontaneous fusion for the sham-operated animals. The fusion masses were more pronounced in Group C than in Group B. Group B demonstrated a dense bony response with continuous trabeculae and
calcification across the disc space, and had no obvious osteophytic growth adjacent to the cortical walls of the C2 and C3 vertebral bodies. However, coupling bony resorption was noted in the central region of the graft. In contrast, full consolidation of fusion masses evidenced by continuing dense cortical bone crossing the disc space was achieved in Group C animals, but this was also accompanied with pronounced osteophytic growths extending beyond anterior and posterior cortical walls of the C2 and C3 vertebral bodies. Our results indicated that Group C had a significantly higher IOD(c) ratio, indicating superior bony fusion across the C2-C3 disc space, than did Group B (0.95 ± 0.03 versus 0.35 ± 0.01, \( P < 0.01 \)). Additionally, the maintenance of disc dimension was better in Group C than in Group B (106.7% ± 4.5 versus 85.4% ± 4.4, \( P < 0.01 \)). However, Group C also had more osteophytes extending beyond the posterior margins of the C2 and C3 vertebral bodies than did Group B (4.1 mm ± 0.2 versus 1.1 mm ± 0.1, \( P < 0.01 \)).

The relative primary rotation data responding to the final load step of 0.72 N-m at the C2-C3 functional unit are illustrated in Figure 2. The results indicate that Group B had the least motion ranges in flexion and lateral bending as well as rotation loads than did the other two groups. Significantly smaller motion ranges of lateral bending and rotation loads were found in Group B than in Group C (\( P < 0.05 \)). Compared to Group A, Group B exhibited significantly smaller motion ranges of flexion, lateral bending, and axial rotation loads (\( P < 0.05 \)). Group C also had decreased motion ranges in flexion and lateral bending loads relative to Group A, but showed a modest increase in the motion range in rotation loads. The motion range in extension load was not significantly different among the three groups.

The relative primary rotation data responding to the final load step of 0.72 N-m at the C3-C4 functional unit are illustrated in Figure 3. Both stabilization groups showed significantly smaller motion ranges in extension and lateral bending loads than Group A, but had a modest increase in the motion range in rotation loads. Compared to Group A, Group B exhibited a significantly smaller motion range of extension and right lateral bending loads (\( P < 0.05 \)), while the motion reduction was not statistically significant in Group C. Additionally, Group B showed a decreased motion range in flexion, relative to Group A, whereas a modest increase of the motion range was seen in Group C.

**Discussion**
Our previous work ascertained that anterior cervical fusion did not completely eliminate the intervertebral motion of the functional unit, presumably as a result of movements at the facet joints [16, 20]. In this experiment, we used a 3-column cervical spine injury model to enhance the residual movements after anterior fusion. With 2 functional units that were simultaneously measured in the pure-moment biomechanical testing, the delayed stability of the destabilized/re-stabilized functional unit and the kinematic influence applied by the cervical musculature under physiological loads over time onto the adjacent functional units could be evaluated. Additionally, the quality of intervertebral bony fusion in the model could be used to decipher the net effects of biomechanical redistribution over time relevant to an implant fixation.

For the C2-C3 functional unit, our results indicate that the anterior plate-stabilized spines provide superior stiffness over time against flexion and lateral bending loads than the posterior-wired spines. The posterior-wired spines are more stable in flexion load than the sham-operated specimens. These findings are compatible with the reported results in human cadaveric spines [32]. One changed finding of the results is that, relative to the sham-operated specimens, the posterior-wired spines have nearly equal stability for the extension and lateral bending loads, indicating that the bone graft maturation over time has improved the stability of extension and lateral bending loads in these posterior-wired spines [16].

The other changed finding of our results for the C2-C3 functional unit is that the posterior-wired spines are not as stable over time as the anterior plate-stabilized spines in the rotation-testing mode [32]. Additionally, a modestly greater motion range of rotation loads was seen at the C3-C4 functional unit in the posterior-wired spines. Thus, decreased stress absorption in rotation of the C2-C3 functional unit might have redistributed the loads applied by the cervical musculature over time, which eventually resulted in modest ligamentous laxity specific to rotation loads at the C3-C4 functional unit in these animals [16, 21]. Conversely, the anterior plate-stabilized spines provided more stability against rotation loads for the C2-C3 functional unit than did the posterior-wired spines and the intact control specimens. Fixation with the anterior plate and screws, therefore, appears to be an effective treatment modality against rotational hypermotility over time.
Although our results, combined with other observations discussed [16, 35], indicated that the anterior-plate fixation provided complementary stability over time against all modes of testing loads for the fixation functional unit, it was, however, noted to associate with a more stiffening adjacent functional unit in extension and lateral bending loads. Actually, the posterior-wired spines also had a modestly decreased motion range of extension and lateral bending loads that occurred at the C3-C4 functional unit. These kinematic changes indicated that both fixation methods would result in a stiffening adjacent functional unit over time in extension and lateral bending loads.

Our results further indicated that Group C animals might have experienced a delayed subclinical event of wire loosening that allows some motion of posterior constructs since the formation of solid anterior fusion masses, theoretically, did not permit a significant amount of residual motion in the rigidly posterior-wired spines [20]. A similar event of wire loosening has been observed in human cadaveric spines in the previous work of Ulrich, et al. [33]. They demonstrated that exclusive posterior wiring was unable to avoid persistent translatory displacement and, eventually, resulted in permanent subluxation of the functional unit with complete discoligamentous instability. In clinical practice, significantly more late pain problems have also been found in patients treated with posterior wiring without in situ structural bone fusion than in those managed with anterior fixation and fusion [8].

Exactly by which mechanism(s) the posterior-wired spines had more osteophytic growths in a condition with fully bony maturation of the graft is (are) not known. Curiously, this pattern of osteophytic growths had also been observed in the C2-C3 discectomied, but not grafted, animals in which the motion ranges of rotation loads simultaneously increased at both the C2-C3 and C3-C4 functional units [16]. It was, therefore, reasonable to infer that the weakness for opposing rotation load might be a significant factor to proceed the formation of osteophytes at the C2-C3 functional unit in the posterior-wired spines. It has been known that solid intervertebral fusion can effectively oppose rotational hypermobility after anterior cervical discectomy [16]. Relative to the sham-operated specimens, the posterior-wired spines substantially had modest increases in the motion range of rotation loads at the C2-C3 and C3-C4 functional units. This finding implies that the formation of solid bony fusion and osteophytes may have contributed to the development of
late stability in rotation loads for these animals. Accordingly, we conclude that the formation of osteophytes in the posterior-wired spines may originate from a self-protective bone-remodeling mechanism of the physiological system acting to compensate for an opposing defect in rotation loads that occurs during the healing process. Further studies, however, need to be performed to determine whether the osteophytes observed in these posterior-wired spines will subsequently absorb after a longer recovery period.

An ideal stabilization method should include dual biomechanical properties not only providing immediate stabilization for the functional unit to be fixed but also allowing an appropriate amount of physiological stresses, applied by the cervical musculature in responding to gravity and normal daily activities, transferring onto the bone graft and the adjacent functional unit [4, 15]. Thus, solid bony fusion can be obtained without deleterious biomechanical effects onto the adjacent functional units. Following the anterior-plate fixation, Group B animals had inferior fusion mass maturation, indicating a relevantly load-shielding effect with the anterior-plate fixation [7, 18]. On the other hand, fixation with posterior wiring would result in superior intervertebral bony fusion. Thus, the posterior-wire fixation might possess more load-sharing properties since the anatomical condition favorable for posterior cervical fusion could not account for this fusion result [9].

Our data, therefore, indicate that increasing the stiffness of an implant fixation will not necessarily lead to a larger fusion mass, although it decreases a potential risk of developing osteophytic formations. Moreover, these results indicate that a rigid implant fixation such as anterior plating may also increase a possibility of developing the stiffening adjacent functional unit, especially in extension and lateral bending loads, although the reasons underlying these findings are not immediately clear.

Although it needs to be stressed that the numbers of animals per group in the present study are low, and that there may be some limitations of applying the current findings from an animal model directly to clinical application in human beings. Our results support that posterior cervical fixation may be an effective method for repairing symptomatic pseudarthrosis following failed anterior cervical fusion [3, 7]. However, the posterior-wire fixation may need the adjuvant use of other fixation methods (i.e., in situ structural bone grafting, facet fusion, and a rigid postoperative orthosis) for limiting rotational hypermotility during healing,
thus decreasing a potential risk of developing osteophytes and wire loosening over time. Additionally, we suggest that intervertebral graft may need to be centrally strengthened so as to improve full maturation of bone graft for patients who will receive an anterior-plate fixation. During a course of the bone-adaptive remodeling process, these anterior plate-stabilized patients may also need to be encouraged to early re-instituting their cervical muscular activities, thereby allowing an appropriate amount of physiological stresses onto the intervertebral graft and decreasing a potential risk of developing adverse stiffness of the adjacent levels.

**Conclusion**

Our results indicated that the anterior-plate fixation was more stable over time than did the posterior-wire fixation, while this biomechanical advantage did not result in larger fusion masses in the former. Exclusive posterior wiring was weak for opposing rotation loads, and this biomechanical defect might be closely related to the formation of osteophytes during a course of the bone-adaptive remodeling process. Our data also indicated that C2-C3 cervical stabilization, regardless of the use of the anterior-plate or posterior-wire fixation, would decrease the motion ranges in extension and lateral bending of the C3-C4 functional unit. These data point out a complex interaction between the stability of an implant fixation and the bone-graft maturation and osteophytic formations as well as the stiffening problems of the adjacent functional units in the implant-stabilized cervical spines.

**Acknowledgements**

This study was supported by the grants from National Science Council, NSC 89-2320-B-006-071 and NSC 91 – 2213 - E006 – 071, and National Cheng Kung University Hospital (NCKUH 89-075)

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