The effects of carpentry on heterotopic ossification and mobility in cervical arthroplasty: determination by computed tomography with a minimum 2-year follow-up

Clinical article

*Tsung-Hsi Tu, M.D.,1–3 Jau-Ching Wu, M.D.,1–3 Wen-Cheng Huang, M.D., Ph.D.,1,2 Ching-Lan Wu, M.D.,2,4 Chin-Chu Ko, M.D.,1,2 and Henrich Cheng, M.D., Ph.D.1–3

1Department of Neurosurgery, Neurological Institute, and 4Department of Radiology, Taipei Veterans General Hospital; and 2School of Medicine and 3Institute of Pharmacology, National Yang-Ming University, Taipei, Taiwan

Object. Heterotopic ossification (HO) after cervical arthroplasty can limit the mobility of an artificial disc. In this study the authors used CT scanning to assess the formation of HO with the goal of investigating the correlation between the carpentry of arthroplasty, formation of HO, mobility, and clinical outcomes.

Methods. A retrospective review of medical records, radiological studies, and clinical evaluations was conducted for consecutive patients who underwent 1- or 2-level cervical arthroplasty with the Bryan disc. The patients underwent follow-up for more than 24 months. The formation of HO was assessed using CT scanning as the final determination. The perfection of carpentry for each arthroplasty level was scrutinized using criteria composed of 2 parameters (postoperative shell kyphosis and inadequate endplate coverage). Levels were divided into the optimal carpentry group and the suboptimal carpentry group. Radiographic and clinical outcomes, including the visual analog scale and neck disability index, were compared between the groups.

Results. A total of 107 levels of Bryan discs were placed in 75 patients (mean age 46.71 ± 9.94 years) and were analyzed. There was a male predominance of 68.0% (51 men), and the mean follow-up duration was 38.56 ± 9.66 months. Heterotopic ossification was identified in 60 levels (56.1%) by CT scanning. Most cases of HO were low grade and did not correlate with the limitation in the segmental motion of the arthroplasty device. There were no significant differences in terms of age, sex, and number of arthroplasty levels between the optimal and the suboptimal carpentry groups. However, the suboptimal carpentry group had significantly more high-grade HO (≥ Grade 2) than the optimal carpentry group (13 levels [12.1%] vs 7 levels [6.5%], p = 0.027). There were also more immobile (range of motion < 3°) artificial discs in the suboptimal carpentry group than the optimal carpentry group (11 levels [10.3%] vs 4 levels [3.7%], p = 0.010). The clinical outcomes (neck and arm visual analog scale scores and Neck Disability Index) in both groups were similarly good.

Conclusions. Shell kyphosis and inadequate endplate coverage have adverse effects on the formation of HO and segmental mobility after cervical arthroplasty with the Bryan artificial disc. Appropriate carpentry is the more important factor in determining the maintenance of segmental motion. Although the midterm clinical outcome remained similarly good regardless of HO, the carpentry of cervical arthroplasty should not be overlooked. Further studies are needed to clarify the etiology of HO.

(http://thejns.org/doi/abs/10.3171/2012.3.SPINE11436)

Key Words • heterotopic ossification • Bryan disc • cervical arthroplasty

Anterior cervical discectomy and fusion is a widely accepted surgical treatment for cervical radiculopathy and/or myelopathy caused by disc herniation and spondylosis.4,5,10,13 The advent of cervical arthroplasty provides the option of motion preservation and the potential to reduce adjacent-segment disease.22,26 Two-year and 5-year reports of cervical arthroplasty have demonstrated the merit of motion preservation at the index level.3,6,12,18,20,34 However, whether the incidence of adjacent-segment disease is reduced by cervical arthroplasty remains unclear.

As longer follow-up periods are anticipated, there are ensuing concerns about failure to maintain motion of the artificial disc. Heterotopic ossification, ectopic bone formation that might cause osseous fusion, was first reported by Parkinson and Sekhon in 2005.21 Subsequently, a number of reports have demonstrated the existence of HO and its potential to compromise the functional mobility of cervical arthroplasty.3,15,17,29 Heterotopic ossification has been identified as one of the major causes of a
limited ROM in the index level of cervical arthroplasty. Interestingly, the reported incidence rates of HO development are substantially inconsistent in different series, ranging from none to more than two-thirds of the treated levels. The true cause of these widely variable incidences of HO in the literature remains elusive. This disparity can be attributed to the design and the material of devices, timing and method of evaluation, the use of NSAIDs, or idiosyncrasy. Furthermore, the long-term effects of HO on clinical outcomes are still uncertain and require investigation.

This study hypothesized that the perfectness of cervical arthroplasty execution is related to its function (that is, mobility) at the index joint, and therefore affects the subsequent development of HO. Apart from arthrosis, arthroplasty aims at restoration of joint function rather than amelioration of motion. In theory, arthroplasty using a Bryan disc installed with ideally executed surgical techniques and positioned as it is designed for is more likely to yield joint mobility mimicking physiological motion than poorly performed operations. This issue should have substantial clinical relevance, but it has not been well addressed in the literature for cervical arthroplasty. Moreover, the 2D overlapping image on plain radiographs, typically used in previous reports, renders the chance of misinterpretation of HO. Therefore, in this series a multidetector CT scan with image reconstruction was used as the final determination of HO to avoid ambiguity.

This report is part of our continuous work and previous publications for comparisons of concordance and discrepancies between plain radiographs and CT scans in the detection of HO. In this study we investigated the correlation of the perfectness of arthroplasty execution and formation of HO, as well as its influence on clinical outcomes.

Methods

This study was approved by the institutional ethics committee, and all patients provided informed consent. Consecutive adult patients who underwent 1- or 2-level cervical arthroplasty with the Bryan disc (Medtronic Spine and Biologics) were retrospectively reviewed.

Surgical Indications and Techniques

Surgical indications included radiculopathy and/or myelopathy from single-level or 2-level cervical disc herniation or spondylosis. Patients with loss of segmental mobility (as a result of spur and facet degeneration, ossification of the posterior longitudinal ligament, or diffuse idiopathic skeletal hyperostosis), target segmental instability (>2 mm translational instability or >15° angular motion), and incompetent facet joints were not candidates for cervical arthroplasty. Also, any of the following conditions were considered inappropriate for cervical arthroplasty in our practice: osteoporosis (T score of <2.5), malignancy, metabolic bone disease, infection or severe systemic diseases, and traumatic disc disease with ligament injury.

Standard anterior cervical discectomy and total disc replacement with the Bryan disc were performed. Gener-
The effects of carpentry on HO and mobility in arthroplasty

TABLE 1: Assessment of the perfection of arthroplasty carpentry

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Condition</th>
<th>Score*</th>
</tr>
</thead>
<tbody>
<tr>
<td>shell kyphosis</td>
<td>no</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>yes</td>
<td>1</td>
</tr>
<tr>
<td>endplate coverage</td>
<td>discrepancy (gap size in mm)</td>
<td>1–2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>&gt;2</td>
</tr>
</tbody>
</table>

* A sum score of 2 points or more indicates suboptimal carpentry.

aspect. A locally kyphotic shell position, that is, an open angle toward the dorsal aspect, was considered suboptimal (Fig. 1). Also, the diameter of the implanted artificial disc should perfectly match the anterior-posterior distance of the indexed vertebral body. Precisely full coverage of the vertebral endplate by the artificial disc shell was anticipated. A shortage in the artificial disc shell size would result in vertebral body endplate exposure, which in this study was also considered suboptimal (Fig. 2).

The proposed grading system used points to evaluate the perfection of carpentry (Table 1). The presence of a kyphotic shell position on postoperative lateral radiographs was designated a score of 1 point. The discrepancy of diameter between vertebral endplate and implant shell on the lateral view was measured and classified into 3 categories: smaller than 1 mm, 1–2 mm, and larger than 2 mm. Each was designated a score of 1, 2, or 3 points, respectively. The sum of these 2 factorial scores (shell kyphosis and endplate coverage discrepancy) added up to sum scores ranging from 1 to 4 points.

A cervical arthroplasty in the proposed optimal carpentry group would receive a total score of 1 point. A sum score of 2 or more indicated suboptimal installation of the implant (presence of shell kyphosis or endplate mismatch > 1 mm). Each cervical arthroplasty in the series was retrospectively classified into either the optimal or suboptimal group. Demographics, radiographic outcomes, and clinical outcomes were then compared.

Statistical Analysis

All statistical analyses were performed using SPSS software (SPSS, Inc.). The Student t-test and paired t-test were used for continuous variables, and the Fisher exact test was applied for categorical data. A probability value < 0.05 was considered statistically significant.

Results

Eighty-eight consecutive adult patients who underwent 1- or 2-level cervical arthroplasty with the Bryan disc were retrospectively reviewed. Seventy-five patients (85.2%) who had complete radiological evaluations with clinical follow-up for more than 2 years were analyzed. The remaining 13 patients were excluded because of inadequate evaluation or failure to provide informed consent, or they were lost to follow-up. A total of 107 levels in 75 patients were evaluated, of whom 43 patients (57.3%) had 1-level and 32 (42.7%) had 2-level cervical arthroplasty. The mean follow-up time was 38.56 ± 9.66 months (range 24–56 months), and the mean CT follow-up time was 26.32 ± 7.18 months (range 12–49 months). The mean age at the time of surgery was 46.71 ± 9.94 years (range 18–68 years), and there was a male predominance at 68.0% (51 men and 24 women). Among the 107 arthroplasty levels, there were 8 (7.5%) at C3–4, 27 (25.2%) at C4–5, 60 (56.1%) at C5–6, and 12 (11.2%) at C6–7 (Table 2).

Demographics of HO Formation

Of the 107 levels of Bryan disc levels evaluated, 60 levels (56.1%) in 41 patients (54.7%) had HO formation detected by CT scanning. According to the grading criteria of McAfee et al., each cervical arthroplasty in the series was retrospectively classified into either the optimal or suboptimal group. Demographics, radiographic outcomes, and clinical outcomes were then compared.
Grade 1 HO, 14 levels (23.3%) of Grade 2, 5 levels (8.3%) of Grade 3, and 1 level (1.7%) of Grade 4 HO. Age and sex were not significant for the patients with or without HO (p = 0.651 and p = 0.060, respectively). Patients with HO formation underwent significantly more 2-level arthroplasty procedures (p = 0.005) (Table 3).

The formation of HO did not affect the clinical outcomes. The clinical outcome measurements of VAS neck, VAS arm, and NDI in the patients with HO formation were not significantly different from those who had no HO (p = 0.812, 0.710, and 0.942, respectively) (Table 3).

**Carpentry of Arthroplasty and HO Formation**

The 107 levels of cervical arthroplasty were evaluated for perfectness of carpentry by using the aforementioned scoring system and were categorized into 2 groups: the optimal carpentry group and the suboptimal carpentry group. Arthroplasty levels in the optimal carpentry group had sum scores of 1 point (that is, no shell kyphosis and endplate discrepancy < 1 mm). On the other hand, the suboptimal carpentry group had levels with sum scores of 2, 3, or 4 points (that is, the presence of shell kyphosis or inadequate endplate coverage with an uncovered gap > 1 mm, or both).

There were 61 levels (57.0%) in the optimal carpentry group and 46 levels (43.0%) in the suboptimal carpentry group. There were no significant differences in age and sex between the groups (p = 0.083 and 0.250, respectively). The distribution of 1-level versus 2-level arthroplasty was not different (p = 0.322) between the optimal and suboptimal groups. The distributions of perioperative NSAID use and indications (soft disc herniation vs spondylosis) between these 2 groups were also not different (p = 0.177 and p = 0.205, respectively) (Table 4). However, regarding the formation of more severe (≥ Grade 2) HO, the suboptimal group had significantly more affected levels than the optimal group (13 [12.1%] vs 7 [6.5%], p = 0.027). In terms of the mobility of the artificial disc, the amount of failed motion preservation of arthroplasty on dynamic lateral radiographs was also significantly different. There were more immobile index levels in the suboptimal carpentry group than in the optimal carpentry group (11 [10.3%] vs 4 [3.7%], p = 0.010) (Table 4).

Most (90.0%) of the cases of HO in this series were less than Grade 3 (66.7% Grade 1 and 23.3% Grade 2), which indicated preserved segmental motion in most of the cases, even though HO existed. Dynamic radiographs showed loss of motion (< 3°) at 15 treated levels (14.0%). Interestingly, 6 of these immobilized discs had no HO. Among the other 9 immobilized discs, 1 had Grade 1 HO, 2 had Grade 2 HO, and 6 had Grade 3 HO.

**TABLE 2: Characteristics of 75 patients who underwent arthroplasty at 107 levels**

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Value†</th>
</tr>
</thead>
<tbody>
<tr>
<td>sex</td>
<td></td>
</tr>
<tr>
<td>male</td>
<td>51 (68.0)</td>
</tr>
<tr>
<td>female</td>
<td>24 (32.0)</td>
</tr>
<tr>
<td>mean age (yrs)</td>
<td>46.71 ± 9.94</td>
</tr>
<tr>
<td>no. of arthroplasty levels</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>43 (57.3)</td>
</tr>
<tr>
<td>2</td>
<td>32 (42.7)</td>
</tr>
<tr>
<td>total</td>
<td>107 (100.0)</td>
</tr>
<tr>
<td>mean CT FU (mos)</td>
<td>26.32 ± 7.18</td>
</tr>
<tr>
<td>mean clinical FU (mos)</td>
<td>38.56 ± 9.66</td>
</tr>
<tr>
<td>level distributions</td>
<td></td>
</tr>
<tr>
<td>C3–4</td>
<td>8 (7.5)</td>
</tr>
<tr>
<td>C4–5</td>
<td>27 (25.2)</td>
</tr>
<tr>
<td>C5–6</td>
<td>60 (56.1)</td>
</tr>
<tr>
<td>C6–7</td>
<td>12 (11.2)</td>
</tr>
</tbody>
</table>

† Mean values are presented as the mean ± SDs. All other values are the number with percentages in parentheses.

* FU = follow-up.

**Fig. 2.** Postoperative lateral radiographs showing measurements of the adequacy of endplate coverage. A and B: An image without (A) and with (B) markers showing inadequate endplate coverage. A discrepancy (gap size) of 2.5 mm and formation of Grade 1 HO (arrow) can be seen. C and D: An image without (C) and with (D) markers showing complete (nicely fitted) endplate coverage. No gap is seen between the posterior borders of the vertebral bodies and the shells.
Clinical Outcomes

The suboptimal carpentry group demonstrated significantly higher rates of immobilized levels (p = 0.010), regardless of HO formation (Fig. 3).

Clinical Outcomes

The carpentry of cervical arthroplasty did not affect the clinical outcomes. The VAS neck and arm scores and NDI were not significantly different between the optimal and the suboptimal carpentry groups preoperatively and at 6-, 12-, and 24-month postoperative time points (Figs. 4 and 5).

Slight anterior migration of the Bryan disc was identified in 1 patient 6 months postoperatively. This patient underwent 1-level surgery and was asymptomatic. The migration was stable and required no revision surgery. Two patients had postoperative hoarseness that recovered 6 months and 1 year postoperatively. There were 2 cases of intraoperative CSF leakage without clinical symptoms or wound complications. One case of C-5 palsy recovered 3 months after surgery. These complications were irrelevant to the carpentry of arthroplasty since they were assessed retrospectively, and there were no other complications (instrument failure, wound infection, deteriorated neurological symptoms, or supplemental fixation) in the series. Thus far, there was has not been any case of reoperation for adjacent-segment disease during the follow-up.

Discussion

This study analyzed 107 levels of cervical arthroplasty (all Bryan disc) in 75 patients with a mean clinical follow-up of more than 3 years (38.6 months). Using CT scans for determining HO successfully minimized errors of interpretation of plain radiographs. In the present study, dynamic radiographs for evaluation of joint mobility at the index level, together with standardized clinical outcome measurements, were comparable to the success of cervical arthroplasty reported elsewhere.3,6,12,18,20,34 Applying self-developed criteria (Table 1) to retrospectively classify the perfection of our arthroplasty procedures using the Bryan disc, 107 levels were divided into 2 groups; there were 61 levels in the optimal carpentry group and 46 levels in the suboptimal carpentry group. Significantly more HO was demonstrated in the suboptimal carpentry group than in the optimal carpentry group (12.1% vs 3.7%, p = 0.010). There were no significant differences in clinical outcomes between the groups, regardless of HO formation or perfectness of carpentry. This study demonstrated, for the first time, the importance of optimization of carpentry for cervical arthroplasty to reduce HO and preserve mobility. Unlike fusion, precise execution of surgical techniques and appropriate implant sizing selection are crucial to restore joint function and thus minimize HO and preserve motion.

The true perfect carpentry of cervical arthroplasty is not well addressed in the literature for any of the market-available artificial discs, despite the fact that each device manufacturer provides specific instructions for insertion. There is a lack of consensus regarding detailed surgical techniques, including size selection and the ideal postoperative radiographic position. The consequences of mediocre cervical arthroplasty are seldom reported. In this study, we attempted to look at the formation of HO and
loss of mobility as undesired results of cervical arthroplasty. After a retrospective review of numerous radiographs of our patients, we developed assessment criteria comprising 2 parameters: shell kyphosis and endplate coverage. First, the shell angle of the cervical artificial disc has been measured in several studies. The concept of shell kyphosis was reported as a design limitation of the Bryan disc that could cause a propensity toward functional spinal unit kyphosis. Postoperative shell kyphosis was regarded as a complication, and some authors have advocated a modified insertion technique to address this problem, although its clinical significance is unclear. Second, the extent of endplate coverage has been a concern for spinal arthroplasty. To position the center of rotation correctly as designed, maximal coverage within the vertebral endplate is commonly accepted by most surgeons. Also, the metallic endplate shell can block ectopic bony outgrowth at the edge. However, how sufficient the coverage should be is questionable.

**Fig. 3.** Lateral neutral and dynamic radiographs showing 2-level cervical arthroplasty in the optimal and the suboptimal carpentry groups. A–C: Images showing optimal carpentry in neutral (A), flexion (B), and extension (C) obtained in one patient. The images show no HO formation and good segmental mobility (full ROM) at both levels. The sum score is as follows: sum score = 1 (no shell kyphosis [0 points], adequate endplate coverage [1 point]). There is no HO and normal mobility (ROM 8°). D–F: Images showing suboptimal carpentry in neutral (D), flexion (E), and extension (F) obtained in another patient. The sum score is as follows: sum score = 4 (shell kyphosis [1 point], inadequate endplate coverage [parallel lines], gap size > 2 mm [3 points]). There is Grade 3 HO (arrowhead) and limited mobility (ROM 3°).

**Fig. 4.** Graph showing the VAS scores for arm and neck pain at each time point. There were no statistically significant differences between the 2 groups at all time points.
The effects of carpentry on HO and mobility in arthroplasty

We noted that some of the published radiographs of HO shared a common feature of inadequacy of coverage at the posterior vertebral endplate (Fig. 6). Therefore, the deficiency of endplate coverage by the artificial disc at the posterior edge of the vertebral body was graded using the proposed criteria (Table 1).

The etiology of HO formation after cervical arthroplasty remains uncertain. Several risk factors such as male sex, hypertrophic osteoarthritis, ankylosing spondylitis, and diffuse idiopathic skeletal hyperostosis have been reported to be associated with HO in large joint arthroplasty in orthopedic experiences. For cervical arthroplasty, older age, male sex, surgical indications, techniques, and multilevel arthroplasty have been suggested in different reports. However, to date there has been a lack of consistent evidence. Investigations are required to corroborate the risk factors and means of prevention.

The incidence rate of HO after arthroplasty is also unclear. A very wide range of occurrence rates has been quoted in different series for devices and for evaluation methods. Suchomel et al. reported that 68% of 60 segments of ProDisc-C (Synthes) arthroplasty had a high grade (≥ Grade 3) of HO at the 4-year follow-up. Beauren et al. reported a rate of 67.1% in 76 levels of Mobi-C (LDR Medical) arthroplasty at the 2-year follow-up. Mehren et al. reported a rate of 66.2% in 77 ProDisc-C arthroplasty levels at 1 year of follow-up. These authors also noted significantly higher rates in multilevel cases. Heidecke et al. quoted a rate of 29% in 59 Bryan discs at the 2-year follow-up. Leung et al. reported a rate of 17.8% in 90 single-level Bryan discs at the 1-year follow-up. All the aforementioned reports evaluated HO using plain radiography. It is reasonable to infer that some ambiguity exists in the interpretation of plain radiographs, especially in cases of low-grade (Grade 1) HO. The only CT-determined HO series was reported by our group with a rate of 48.1% in 52 levels of Bryan discs at an average of 19 months of follow-up. Although there is quite a discrepancy in the incidences of HO in the aforementioned reports, they all uniformly claimed that most of the HO did not affect clinical outcomes of arthroplasty. It is also reasonable to infer that low-grade HO does not usually compromise segmental motion. Nevertheless, many other issues could cause the loss of motion in cervical arthroplasty, such as device design and facet degeneration. This can be corroborated by the fact that, in the present series some cases of limited segmental motion did not have HO at all.

The prescription of NSAIDs is a popular practice for prevention of HO. The first 3 large, multicenter, prospective, randomized US Food and Drug Administration–approved investigational device exemption studies compared the PRESTIGE ST (Medtronic), Bryan, and ProDisc-C cervical arthroplasty procedures with anterior cervical discectomy and fusion for single-level disc diseases. In these trials, NSAIDs were routinely prescribed. At the 2-year follow-up of the more than 600 arthroplasty levels, formation of HO with osseous fusion was reported in 1 patient with a PRESTIGE ST disc, no patient with a Bryan disc, and 3 patients with ProDisc-C arthroplasty. In particular, the Bryan trial showed no spontaneous fusion at 2 years. The excellent mobility of these artificial discs was attributed to the prescription of NSAIDs for 2 weeks postoperatively, as well as to patient selection to exclude those with severe spondylosis, who were more likely to exhibit fusion. These well-executed trials also implied the importance of technical issues in cervical arthroplasty surgery. Surgeon expertise might account for the scarcity of HO in these 3 trials, as the results of our current study indicated that the carpentry of arthroplasty could play a role.

The merits of this study are single artificial disc design (Bryan), the uniformly performed surgical techniques by the same group, and CT determination of HO.
Plain radiographs are convenient and usually sufficient in most clinical scenarios, but the 2D nature inherently allows error. Thin-slice axial CT scans with sagittal and coronal reformatted images can better scrutinize the details of the bone structure, especially in the determination of low-grade HO. A prudent definition of HO is necessary for this kind of study investigating the causes of HO. Moreover, the patients’ characteristics were relatively uniform, including ethnicity, surgery (surgeons in 1 group), and perioperative management (that is, the use of NSAIDs).

There are limitations to our study. First, our criteria for judging carpentry were simplified and improvised. A caveat is that several other critical elements, including midline identification, coronal balance, and extent of neural foraminal decompression, were not included. The omission certainly does not imply neglect, but rather facilitates the understanding of the common errors of our practice. Only in hindsight do frequently overlooked issues in cervical arthroplasty become apparent. Precisely performed arthroplasty is essential to achieve a satisfactory outcome. Second, although detection of HO by CT scanning is more accurate, it is not a means of evaluation that can be frequently used because of the excessive cost and potentially increased radiation exposure. Third, this study only included arthroplasty with Bryan discs. Therefore, whether the results can be applied to other arthroplasty devices remains questionable. Of no doubt, the formation of HO is multifactorial. A specific study design with multivariate regression analysis of larger numbers and longer follow-up periods will better clarify the issue.

Conclusions

Shell kyphosis and inadequate endplate coverage have adverse effects on the formation of HO and segmental mobility after cervical arthroplasty with the 1- and 2-level Bryan artificial disc procedures. Appropriate carpentry is the more important factor in determining the maintenance of segmental motion. Although the midterm clinical outcome remains similar, the carpentry of cervical arthroplasty should not be overlooked.

Disclosure

The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

Author contributions to the study and manuscript preparation include the following. Conception and design: Tu, JC Wu, Huang. Acquisition of data: Ko, Tu, CL Wu. Analysis and interpretation of data: Tu, JC Wu. Drafting the article: Tu, JC Wu. Critically revising the article: all authors. Reviewed submitted version of manuscript: all authors. Approved the final version of the manuscript on behalf of all authors: Ko. Statistical analysis: Tu. Administrative/technical/material support: Huang, CL Wu, Cheng. Study supervision: JC Wu, Huang, Cheng.

References

The effects of carpentry on HO and mobility in arthroplasty


Manuscript submitted May 9, 2011.
Accepted March 5, 2012.
Please include this information when citing this paper: published online March 30, 2012; DOI: 10.3171/2012.3.SPINE11436.
Address correspondence to: Chin-Chu Ko, M.D., Department of Neurosurgery, Neurological Institute, Taipei Veterans General Hospital, Room 509, 17F, No. 201, Shih-Pai Road, Sec. 2, Beitou, Taipei 11217, Taiwan. email: hansamu0627@gmail.com.