Differences between C3–4 and other subaxial levels of cervical disc arthroplasty: more heterotopic ossification at the 5-year follow-up

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OBJECTIVE Several large-scale clinical trials demonstrate the efficacy of 1- and 2-level cervical disc arthroplasty (CDA) for degenerative disc disease (DDD) in the subaxial cervical spine, while other studies reveal that during physiological neck flexion, the C4–5 and C5–6 discs account for more motion than the C3–4 level, causing more DDD. This study aimed to compare the results of CDA at different levels.

METHODS After a review of the medical records, 94 consecutive patients who underwent single-level CDA were divided into the C3–4 and non-C3–4 CDA groups (i.e., those including C4–5, C5–6, and C6–7). Clinical outcomes were measured using the visual analog scale for neck and arm pain and by the Japanese Orthopaedic Association scores. Postoperative range of motion (ROM) and heterotopic ossification (HO) were determined by radiography and CT, respectively.

RESULTS Eighty-eight patients (93.6%; mean age 45.62 ± 10.91 years), including 41 (46.6%) female patients, underwent a mean follow-up of 4.90 ± 1.13 years. There were 11 patients in the C3–4 CDA group and 77 in the non-C3–4 CDA group. Both groups had significantly improved clinical outcomes at each time point after the surgery. The mean preoperative (7.75° vs 7.03°; p = 0.58) and postoperative (8.18° vs 8.45°; p = 0.59) ROMs were similar in both groups. The C3–4 CDA group had significantly greater prevalence (90.9% vs 58.44%; p = 0.02) and higher severity grades (2.27 ± 0.3 vs 0.97 ± 0.99; p = 0.0001) of HO.

CONCLUSIONS Although CDA at C3–4 was infrequent, the improved clinical outcomes of CDA were similar at C3–4 to that in the other subaxial levels of the cervical spine at the approximately 5-year follow-ups. In this Asian population, who had a propensity to have ossification of the posterior longitudinal ligament, there was more HO formation in patients who received CDA at the C3–4 level than in other subaxial levels of the cervical spine. While the type of artificial discs could have confounded the issue, future studies with more patients are required to corroborate the phenomenon.

KEY WORDS cervical disc arthroplasty; heterotopic ossification; C3–4

Several prospective randomized control trials by the US FDA on cervical disc arthroplasty (CDA), with up to 7 years of follow-up,5,6,8–10,15,21,22,29 demonstrate the maintenance of improved clinical outcomes with the preservation of disc mobility after 1- or 2-level CDA.13,14,25 In these FDA trials, the inclusion criteria for CDA were patients with symptomatic degenerative disc disease (DDD) refractory to medical treatment at the C3–7 levels.15,21,22,30 Thus, in many reports, CDA has been commonly accepted as a viable surgical option for the subaxial cervical spine.11,20,29,33–37

Biomechanical studies reveal that each level of the subaxial cervical spine shares the axial load and contributes to the global motion of the neck, with slight differences.5,12,16,31,41 For example, the range of motion (ROM) and instantaneous axes of rotation for every vertebral
level from C-3 to C-7 vary individually, even in healthy individuals. During neck flexion and extension, the C3–4 disc has less ROM than the C4–5 or C5–6 discs, which correlates with the reported higher incidence of DDD that requires surgery at the C4–5 and C5–6 levels than at C3–4.11,29,34,36 These slight differences may not be an issue in the standard anterior cervical discectomy and fusion (ACDF) once arthrosis is achieved. However, unlike ACDF, the results of CDA depend on how well joint function is restored. Thus, CDA requires perfectly executed surgical techniques in prudently selected patients in order to achieve good results.

Since the techniques of CDA are more demanding than those for ACDF,17 the C3–4 disc has less ROM, and the surgical approach for C3–4 is slightly more troublesome, it is reasonable to raise concern regarding whether the C3–4 disc is a good candidate for CDA. Nevertheless, the FDA trials do not provide details for each level (e.g., C3–4, C4–5, C5–6, or C6–7), and the outcomes of CDA at each specific level of the subaxial cervical spine have never been reported. This retrospective study aimed to compare the radiographic and clinical outcomes of CDA at C3–4 (i.e., the disc with the least ROM) to those of the other levels of the subaxial cervical spine. The formation of heterotopic ossification (HO) was determined using CT, and the clinical outcomes were evaluated by standardized outcome measurements that were adopted in many FDA trials.

Methods

This study reviewed the radiographic and clinical data of 94 consecutive patients who underwent single-level CDA at the C3–7 levels between July 2007 and March 2012 at Taipei Veterans General Hospital.

Inclusion and Exclusion Criteria

The surgical indications were radiculopathy and/or myelopathy caused by cervical DDD or spondylosis that did not adequately respond to at least 12 weeks of conservative treatment. Patients with ossification of the posterior longitudinal ligament (OPLL), previous cervical spine operations, concomitant cervical fusion or disc replacement surgery at other levels, osteoporosis (T-score < −2.5), malignancy, metabolic bone disease, inflammatory spondyloarthritis (e.g., rheumatic arthritis, psoriatic arthritis), active infection, or severe systemic diseases (e.g., cirrhosis of the liver) were excluded.

Patients who were included underwent postoperative follow-up at the outpatient clinics at 3, 6, 12, and 24 months. Those who did not undergo follow-up beyond the 6-month follow-up were defined as “lost to follow-up,” and only the remaining 88 patients were included in the final analysis.

Operative Techniques

The patient was placed supine under general anesthesia. A right-sided horizontal incision was made along a skin crease that correlated to the targeted cervical level. Generous decompression was routinely performed, including bilateral uncovertebrectomy and resection of the posterior longitudinal ligament, prior to the placement of the artificial discs. Much care was used in the preparation of the endplates and selection of the proper size of the implants. During the entire process, copious irrigation with normal saline was performed when drilling the osteophytes. A closed-drain system was routinely placed before wound closure. In this series, Bryan (Medtronic), Prestige LP (Medtronic), or ProDisc-C (DePuy Synthes) artificial discs were used as implants.

Clinical and Radiographic Evaluations

Standard anteroposterior, lateral, and lateral dynamic (flexion/extension) radiographs were obtained in the preoperative and immediate postoperative periods (within 3 days) and at 3, 6, 12, and 24 months postoperatively. Segmental motion was defined by the difference in the Cobb angle at the indicated level between the flexion and extension radiographs, as measured by the quantitative analysis software SmartIris (Taiwan Electronic Data Processing Co.). The loss of mobility at the index level after surgery was defined as an ROM < 3° on lateral dynamic radiographs.

Multidetector, thin-section CT scans with reconstruction images were obtained at follow-up visits more than 12 months after surgery. CT imaging was used for the final determination and grading of HO if there was any ambiguity or discrepancy. The grading of HO was based on the classification proposed by McAfee et al.17 Radiographic interpretations were made by independent radiologists and 2 neurosurgeons.

Clinical outcome assessment was made during the same clinical visit by 2 special nurse assistants using the visual analog scale (VAS) and the Japanese Orthopaedic Association (JOA) scale under the supervision of physicians. Any ambiguity was resolved by the on-site neurosurgeons.

Statistical Analysis

Independent and paired t-tests were used for analysis of the continuous variables using Excel software (Microsoft Inc.). Statistical significance was set at p < 0.05. All values in the text and tables are presented as the mean ± standard deviation.

Results

Overall Demographics

Of the 94 patients, 88 (93.61%) patients who completed the follow-up studies were included in the analysis. Six patients had to be excluded because they were lost to follow-up after being discharged from the hospital, and a true evaluation of the clinical outcome was unavailable. The mean follow-up time of the entire group was 4.90 ± 1.13 years. There were 47 (53.4%) male and 41 (46.6%) female patients with a mean age of 45.62 ± 10.91 years at the time of surgery. The mean ROM at the indicated level was 7.11° ± 4.57° preoperatively and 8.42° ± 5.52° postoperatively (Table 1).

In terms of the cervical artificial discs that were applied in this series, there were 30 Bryan discs (34.1%), 48 ProDisc-C discs (54.5%), and 10 Prestige LP discs (11.4%).
The distributions of the different artificial discs are illustrated in Fig. 1.

**C3–4 Versus Non-C3–4 Disc Arthroplasty**

The 88 patients analyzed in the study were divided into 2 groups: the C3–4 group, which was composed of 11 patients (12.5%) who underwent single-segment CDA at the level of C3–4; or the non-C3–4 group, which was composed of the remaining 77 patients (87.5%) who had the same surgery at the level of C4–5, C5–6, or C6–7 (n = 12, 61, and 4, respectively).

The demographic data of both groups were similar (Table 1). The mean age of patients in the C3–4 group was 36.61 ± 13.10 years, which was less than the mean age of patients in the non-C3–4 group (46.89 ± 9.87 years; p = 0.003). In terms of sex, there was a predominance of male patients in the C3–4 group (male/female ratios 9:2 and 38:39, respectively). The mean follow-up duration was slightly longer in the non-C3–4 group (4.91 ± 1.15 years) than in the C3–4 group (4.81 ± 0.98 years), but the difference did not reach statistical significance (p = 0.77).

Clinical evaluations demonstrated significant improvement postoperatively in both groups. The mean postoperative VAS-neck, VAS-arm, and JOA scores in both groups were significantly improved in nearly all different time sets of follow-up in comparison with the preoperative scores (Figs. 2–4). There were no significant differences between the 2 groups at each time point.

The radiographic evaluations of both groups demonstrated similar mobility after CDA (Table 2). The mean preoperative motion in the C3–4 group was 7.75° ± 4.17°, which was similar to that in the non-C3–4 group (7.03° ± 4.49°; p = 0.67). The postoperative motions in the C3–4 and the non-C3–4 groups were 8.18° ± 5.49° and 8.45° ± 5.55°, respectively, but these did not reach statistical significance. Regarding the formation of HO, 10 of the 11 patients (90.9%) in the C3–4 group and 45 patients (58.4%) in the non-C3–4 group developed HO (p = 0.02). Aside from differences in the incidence rate of HO formation, the severity of HO based on McAfee’s classification system also demonstrated significant differences (2.27 ± 0.30 vs 0.97 ± 0.99; p = 0.0001) between the 2 groups. Patients in the C3–4 group had more severe HO (higher McAfee grade) than patients in the non-C3–4 group (Figs. 5 and 6). Interestingly, although HO was detected in a substantial number of patients in the present series, a majority of the artificial discs remained mobile at the last follow-up (90.9% in the C3–4 group vs 80.5% in the non-C3–4 group; p = 0.41). Overall, 55 (62.5%) patients had HO, and 41 (74.5%) of these patients remained mobile at nearly 5 years of follow-up.

In the present series, no patients required secondary surgery (e.g., revision, removal of an implant, or conversion to fusion). Two patients (2.3%) developed temporary hoarseness postoperatively that resolved at the 6-month follow-up. One patient (1.1%) experienced intraoperative dural leakage due to inadvertent abrasion from the surgical instruments. The leakage was minor and sealed intraoperatively using tissue glue (Tisseel, Baxter). The patient had no postoperative neurological deficit or wound problems on discharge or at the subsequent follow-up visits. No other complications were identified at the most recent follow-up, and no patient required a second surgery for symptomatic adjacent-segment disease.

**TABLE 1. Demographic data of the study cohort***

<table>
<thead>
<tr>
<th>Characteristics†</th>
<th>Value</th>
<th>No. w/ HO (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male/female ratio</td>
<td>47:41</td>
<td></td>
</tr>
<tr>
<td>C3–4</td>
<td>9:2</td>
<td></td>
</tr>
<tr>
<td>Non-C3–4</td>
<td>38:39</td>
<td></td>
</tr>
<tr>
<td>Mean age ± SD, yrs</td>
<td>45.62 ± 10.91</td>
<td></td>
</tr>
<tr>
<td>C3–4</td>
<td>36.61 ± 13.10</td>
<td></td>
</tr>
<tr>
<td>Non-C3–4</td>
<td>46.89 ± 9.87</td>
<td></td>
</tr>
<tr>
<td>Mean clinical follow-up ± SD, yrs</td>
<td>4.90 ± 1.13</td>
<td></td>
</tr>
<tr>
<td>C3–4</td>
<td>4.81 ± 0.98</td>
<td></td>
</tr>
<tr>
<td>Non-C3–4</td>
<td>4.91 ± 1.15</td>
<td></td>
</tr>
<tr>
<td>Surgical levels</td>
<td>88</td>
<td></td>
</tr>
<tr>
<td>C3–4</td>
<td>11</td>
<td></td>
</tr>
<tr>
<td>Non-C3–4</td>
<td>77</td>
<td></td>
</tr>
<tr>
<td>Mean preop motion ± SD, °</td>
<td>7.11 ± 4.57</td>
<td></td>
</tr>
<tr>
<td>C3–4</td>
<td>7.75 ± 4.17</td>
<td></td>
</tr>
<tr>
<td>Non-C3–4</td>
<td>7.03 ± 4.49</td>
<td></td>
</tr>
<tr>
<td>Postop motion ± SD, °</td>
<td>8.42 ± 5.52</td>
<td></td>
</tr>
<tr>
<td>C3–4</td>
<td>8.18 ± 5.49</td>
<td></td>
</tr>
<tr>
<td>Non-C3–4</td>
<td>8.45 ± 5.55</td>
<td></td>
</tr>
<tr>
<td>Bryan discs (no.)</td>
<td>30</td>
<td>15 (50)</td>
</tr>
<tr>
<td>C3–4</td>
<td>5</td>
<td>4 (80)</td>
</tr>
<tr>
<td>Non-C3–4</td>
<td>25</td>
<td>1 (44)</td>
</tr>
<tr>
<td>ProDisc-C discs (no.)</td>
<td>48</td>
<td>35 (72.92)</td>
</tr>
<tr>
<td>C3–4</td>
<td>5</td>
<td>5 (100)</td>
</tr>
<tr>
<td>Non-C3–4</td>
<td>43</td>
<td>30 (69.77)</td>
</tr>
<tr>
<td>Prestige LP discs (no.)</td>
<td>10</td>
<td>5 (50)</td>
</tr>
<tr>
<td>C3–4</td>
<td>1</td>
<td>1 (100)</td>
</tr>
<tr>
<td>Non-C3–4</td>
<td>9</td>
<td>4 (44.44)</td>
</tr>
</tbody>
</table>

* Values are presented as the number of patients (%) unless stated otherwise.
† The non-C3–4 levels included C4–5, C5–6, or C6–7.
More HO in cervical arthroplasty at C3–4

Discussion

This is the first study that specifically compares CDA at the level of C3–4 to that at other levels of the subaxial cervical spine. This retrospective cohort includes 88 consecutive patients who were treated by 1-level CDA using artificial Bryan, Prestige LP, or ProDisc-C discs. The mean age at surgery was 45.6 years, and the mean follow-up duration was approximately 5 years. After dividing the 88 patients into the C3–4 and non-C3–4 groups, there were no significant preoperative differences in the mean ROM of the index level between the 2 groups (7.75° vs 7.03°; \( p = 0.58 \)). Postoperatively, the mean ROM was similarly preserved (8.18° vs 8.45°; \( p = 0.59 \)). Furthermore, both of the groups had similar postoperative clinical improvements in the VAS-arm, and VAS-neck, and JOA scores at each of the follow-up time points. However, there was a significantly higher prevalence of HO in the C3–4 group than in the non-C3–4 group (90.9% vs 58.4%; \( p = 0.02 \)). HO in the C3–4 group was also more severe than that in the non-C3–4 group (\( p < 0.001 \)). Although most of the artificial discs remained mobile in both groups (90.1% and 80.5%), the current study raises the concern of CDA at the level of C3–4. The etiology of this phenomenon remains unclear and warrants further investigation.

The exact cause of HO formation after CDA is vague. Previous studies suggest risk factors, including advanced age, male sex, surgical techniques, preexisting uncovertebral joint hypertrophy, surgical indications, types of prosthesis, multilevel disease, and postoperative biomechanical changes.7,27–29,34–36,39,40 CDA, rather than ACDF as the standard of care, aims to restore joint function. Theoretically, if the artificial disc can completely function with its physiological motion at the indexed level, the likelihood

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**Fig. 2.** Clinical outcomes at different time points of evaluation, as measured by the VAS score for arm pain in the C3–4 and non-C3–4 groups, revealed no significant difference between the 2 groups at each time point. *Significant improvement in comparison with the preoperative scores.

**Fig. 3.** Clinical outcomes at different time points of evaluation, as measured by the VAS score for neck pain, revealed no significant difference between the 2 groups at each time point. *Significant improvement in comparison with the preoperative scores.
of HO formation will be low. There are also built-in differences in the biomechanics between each level of the cervical spine, including the segmental contribution to the global ROM and instant center of rotation.1–3,19,24,27,38

Miller et al. reported that the correlation between neutral cervical posture and flexion or extension ROM was only strong at the C-4 and C-5 levels.19 Wu et al. demonstrated that neck flexion relied more on the middle cervical segments and less on the lower ones, and vice versa during extension.38 Considering the biomechanics, the instant center of rotation can change significantly for each successive motion segment from C2–3 to C6–7, and the kinematics of axial rotation are also altered after CDA in the C3–4 segment.1,32 The higher prevalence and severity of HO at the level of C3–4, as shown here, implies that the currently available, universal (i.e., 1 kind for all levels) design of artificial discs may not be ideal. A tailor-made device that can obtain better carpentry or natural ROM specifically for C3–4 may reduce unintended HO.

Most of the published biomechanical studies use finite models, cadaver samples, or healthy volunteers, rather than the spondylotic spine that is frequently managed in actual clinical practice. Thus, the disparity between a normal spine and a spondylotic spine caused by DDD may be omitted. The formation of HO after surgery may be caused by ongoing spondylosis, as the CDA procedure itself is unlikely to halt the process of degeneration. Therefore, HO would be identified more commonly in the cervical spine, which has more degeneration.34,36 The significantly greater incidence of HO at C3–4 associated with CDA may be multifactorial due to the biomechanical design of the arthroplasty device, the nature of spondylosis, the perfection of the surgical implantation, and idiosyncrasies.

The exact incidence of HO formation after CDA also remains elusive. The reported incidence of HO ranges from none to more than two-thirds of patients in different series. Such variance may be attributed to the indications for surgery, the perioperative administration of nonsteroidal antiinflammatory drugs, surgical techniques, and methods for the detection and determination of HO.34,35 It is reasonable to have substantially lower incidences of HO in studies that use plain radiography for screening. On the other hand, studies that use CT scans to determine HO may be more sensitive and inevitably yield higher incidences of HO.

In the current series, the surgical procedures and perioperative management were similar to those of major FDA trials and in concordance with previous serial studies.11,28,29,34–36 Thus, this study minimized the influences of these external variables and focused on the fundamental, internal (i.e., interlevel) differences.

The rostral-most, subaxial, cervical spinal segment (i.e., the C3–4 disc level) is of special interest because it is technically more demanding to obtain adequate exposure for optimal carpentry during CDA.29 More frequent problems with singing are reported if the C3–4 disc is included in the ACDF.42 Mehra et al. also demonstrated that the surgical approach to the cervical spinal levels above C-4 can significantly increase the risk of voice and swallowing difficulties after ACDF.29 Although C3–4 disc herniation is remarkably less common than C4–5 or C5–6 herniation, anterior cervical discectomy in such cases is often still inevitable. The FDA trials never specifically analyzed the efficacy of CDA at the level of C3–4 and its related adverse effects, which is the impetus for the current investigation.

**Table 2. Radiological outcomes**

<table>
<thead>
<tr>
<th>Variable</th>
<th>C3–4</th>
<th>Non-C3–4*</th>
<th>p Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of patients</td>
<td>11</td>
<td>77</td>
<td></td>
</tr>
<tr>
<td>Mean preop ROM ± SD, °</td>
<td>7.75 ± 4.17</td>
<td>7.03 ± 4.49</td>
<td></td>
</tr>
<tr>
<td>Mean postop ROM ± SD, °</td>
<td>8.18 ± 5.49</td>
<td>8.45 ± 5.55</td>
<td></td>
</tr>
<tr>
<td>No. w/ HO</td>
<td>10 (90.90%)</td>
<td>45 (58.44%)</td>
<td>0.02†</td>
</tr>
<tr>
<td>Class of HO ± SD‡</td>
<td>2.27 ± 0.30</td>
<td>0.97 ± 0.99</td>
<td>0.0001†</td>
</tr>
<tr>
<td>No. of immobile discs</td>
<td>1 (9.1%)</td>
<td>15 (19.5%)</td>
<td></td>
</tr>
</tbody>
</table>

* Other single-segment CDA involved in this study was at the level of C4–5, C5–6, or C6–7.
† Comparison between the C3–4 and non-C3–4 groups.
‡ Based on the classification system of McAfee et al.
The limitations of this study are its retrospective, nonrandomized, noncontrolled design with its relatively small sample size, especially in the C3–4 group. Eleven patients who underwent C3–4 CDA were compared with 77 patients who underwent CDA at the C4–5, C5–6, or C6–7 level. However, C3–4 disc herniation itself is far less commonly seen in clinical practice, and this relatively low percentage of C3–4 was a universal issue among the published FDA investigational device exemption trials on CDA. For example, the ProDisc-C trial included only 3 patients who received C3–4 CDA among 103 enrolled patients.22 There were 7 patients who received C3–4 CDA among the 136 patients in the Kineflex|C trial,9 but none of the 218 patients in the PCM® (Nuvasive) trial.23 In the 5- to 7-year reports of the trials for the Prestige and Bryan discs, the exact number of C3–4 CDAs was not disclosed.5,6,15 However, 1 Bryan disc at C3–4 among the 56 patients who underwent CDA was reported in 2007.26 After summation, only 11 cases of CDA have been documented at the C3–4 level in more than 500 patients. The current series includes 11 cases of C3–4 CDA among 88 patients (12.5%), which is the largest series of C3–4 CDA reported to date. Although these 11 cases are historically comparable to those in the literature, they may not form a substantive basis to decide whether CDA is efficacious for C3–4 disc herniation.

Another limitation is the innate differences between individual patients. Ideally, C3–4 CDA needs to be compared with other levels of CDA within the same patient in order to eliminate intersubject variability. However, this concern may be overlooked since the demographic data (Table 1) were similar between the 2 groups.

There are also a number of confounding factors regarding the prevalence of HO formation demonstrated in the present study. The Asian population has a propensity to have OPLL and diffuse idiopathic skeletal hyperostosis, which can account for the relatively high incidence of HO in the current series. Also, among the 11 CDA cases at
the C3–4 level, there were 3 kinds of devices installed (5 Bryan, 5 ProDisc-C, and 1 Prestige LP discs). Obviously, CDA at C3–4 only accounted for a small portion of the patients who received these 3 devices (16.7%, 10.4%, and 10.0%, respectively), while the rate of HO formation of C3–4 CDA was universally high for the 3 kinds of devices (80%, 100%, and 100% for Bryan, ProDisc-C, and Prestige LP, respectively) (Table 1). The numbers were not adequate for analysis. While we acknowledge that the different biomechanics and materials of the artificial discs could also affect these issues, and thus require further studies to clarify, we nevertheless demonstrate, consistent with our main argument and evidence, that HO formation was high at the C3–4 level when compared with other levels. Given that there is a paucity of available data about CDA at C3–4, further investigations with larger sample sizes and longer follow-up periods are required to corroborate this phenomenon. The discrepancy between CDA at C3–4 and other subaxial cervical segments merits future validation.

Conclusions

Although CDA at the C3–4 level was infrequent, the improved clinical outcomes of CDA were similar in the C3–4 cases to those at other subaxial levels of the cervical spine (C4–5, C5–6, and C6–7) at the approximately 5-year follow-up points. In this Asian population, who had a propensity to have OPLL and diffuse idiopathic skeletal hyperostosis, there was more HO formation in patients who received CDA at the C3–4 level than in the other subaxial levels of the cervical spine. However, the type of artificial discs could also confound the issue, and future studies with larger sample sizes are required to corroborate the phenomenon.

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Disclosures
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
Conception and design: JC Wu, PY Chang, HK Chang, CL Wu. Acquisition of data: JC Wu, PY Chang. Analysis and interpretation of data: JC Wu, PY Chang. Drafting the article: JC Wu, PY Chang, HK Chang. Critically revising the article: JC Wu, PY Chang, Fay, Tu. Reviewed submitted version of manuscript: JC Wu, PY Chang, HK Chang, Huang, Fay, CL Wu. Approved the final version of the manuscript on behalf of all authors: JC Wu. Statistical analysis: JC Wu, PY Chang, Huang, Fay, Tu, Cheng. Administrative/technical/material support: JC Wu, PY Chang, Huang, Tu, Cheng. Study supervision: CL Wu, Cheng.

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