Apical segmental resection osteotomy with dual axial rotation corrective technique for severe focal kyphosis of the thoracolumbar spine

Clinical article

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Object. In this paper, the authors’ goal was to evaluate the feasibility, safety, and efficacy of apical segment resection osteotomy with dual axial rotation correction for severe focal kyphosis by examining outcomes.

Methods. Between May 2004 and December 2006, the authors treated 23 patients with severe focal kyphosis (average Cobb angle 86.9°, range 50°–130°) using apical segmental resection osteotomy with dual axial rotation correction and instrumented anterior column reconstruction and fusion. Radiographic assessment of sagittal plane balance and kyphotic Cobb angle (including a scoliosis Cobb angle in 9 cases) was performed in each patient before and immediately after surgery and at the last follow-up (minimum 2 years). The Frankel grading system for neurological function and Oswestry Disability Index for quality of life were evaluated before surgery and at the last follow-up. The patient satisfaction index was also used for clinical evaluation at the last follow-up.

Results. The mean surgical time was 6.7 hours. The average blood loss was 2960 ml. All patients underwent follow-up for 2 or more years after surgery. The fusion rate was 95.65%. The average kyphotic angle improved from 86.9° preoperatively to 25.6° immediately postoperatively, with an average correction rate of 72.17%. At the last follow-up, the average kyphotic angle was 27.4°, making the final correction rate 69.87%. The sagittal plane balance was significantly improved at the last follow-up. Preoperatively, 15 patients had neurological deficits, and the Frankel grade was E in 8 cases, D in 8 cases, C in 6 cases, and B in 1 case. At the last follow-up, 15 cases were Grade E, 5 were Grade D, and 3 were Grade C. The average improvement in the Oswestry Disability Index score was 43.30%. The patient satisfaction index result showed a total satisfaction rate of 91.30%. Complications included 1 case of late neurological deficit due to shifting of an expandable artificial vertebra, 5 cases of nerve root injury, 3 cases of dural tear, and 1 case of transient lower-extremity weakness due to insufficient blood supply to the spinal cord during surgery.

Conclusions. Apical segmental resection osteotomy with dual axial rotation correction and instrumented fusion is an effective and safe way to treat severe focal kyphosis of the thoracolumbar spine.

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Key Words • apical segmental resection • focal kyphosis • dual axial rotation correction • spinal correction

SHARP focal kyphosis of the thoracolumbar spine is most commonly reported in cases of congenital kyphosis, old vertebral tuberculosis, and malunited fractures of the spine. This type of deformity can compromise the spinal cord or lead to severe low-back pain. Furthermore, kyphosis can cause severe psychological problems. Since 1985, when Thomasen18 first reported a transpedicular closing wedge osteotomy in treating ankylosing spondylitic kyphosis, this technique has been widely used for correcting kyphosis of various kinds with good results.3,4,17,19 A kyphotic angle less than 40° can be effectively corrected with this method, whereas more extensive correction may lead to over-shortening and injury to the spinal cord.5,8,11 Therefore, some authors have suggested performing single or multiple corpectomy and closing osteotomy techniques for the treatment of severe kyphosis.7,13 However, the correction rate has only been around 50%, and some patients have suffered neurological injuries. Anterior release combined with posterior osteotomy is another choice of corrective technique proposed by some surgeons.1,12,14,16 but multiple approaches are needed, and the results for severe kyphosis are not better than those obtained with the aforementioned methods.1,16 In cases in which the kyphotic angle is greater than 90° or those in which the apex of the kyphosis contains multiple fused vertebrae, the rigid severe deformity,
overlapped rib, and distorted fragile spinal cord can make the correction extremely difficult. Thus, we extended the osteotomy to the entire apical area of kyphosis with the addition of dual axial rotation correction and reconstruction of the anterior column.

Methods

Patient Population

Between May 2004 and December 2006, 23 consecutive patients (10 male and 13 female patients) with severe focal kyphosis were treated with apical segmental resection osteotomy, dual axial rotation correction, and instrumented anterior column reconstruction and fusion. The mean age was 34.3 years (range 11–65 years). In this series, 15 patients had leg numbness and/or weakness, 4 had severe back pain, and 4 required surgery for cosmetic purposes only. With the exception of these 4 patients, all had undergone brace or medication treatment. The inclusion criterion for this surgical technique was either a kyphotic Cobb angle greater than 60° or a kyphotic apex comprising multiple fused or malformed vertebrae. Congenital hemivertebrae were diagnosed in 8 patients, kyphosis due to a past tuberculosis infection in 12, post-traumatic kyphosis in 2, and post–spinal tumor resection surgery, including 4 with tuberculous lesion elimination, 1 with vertebral infection surgical correction surgery, 1 with posterior decompression, and 1 patient with repeated tumor resection.

Radiological and Clinical Assessment

Radiological assessment included regional kyphosis and full spine AP and lateral radiographs as well as CT and MR imaging. Local kyphosis and scoliosis Cobb angles and sagittal plane balance were measured before surgery, immediately after surgery, and at the last follow-up (minimum 2 years). The measurement of sagittal plane balance was the distance from the C-7 plumb line to the posterior-superior corner of S-1 or the sacral promontory. Negative sagittal imbalance was posterior falling to the posterior-superior corner of S-1 of the C-7 plumb line; positive sagittal imbalance was anterior falling to the sacral promontory of the C-7 plumb line. If the C-7 plumb line fell between the posterior-superior corner of S-1 and the sacral promontory, a well-balanced condition was diagnosed in 1 patient. The locations of the kyphotic apex were at the midlumbar spine (in 2 patients), the thoracolumbar segment (in 9), and the upper and middle thoracic spine (in 12). Nine patients had undergone previous surgery, including 4 with tuberculosis lesion elimination, 1 with tuberculous abscess suction, 2 with posterior correction surgery, 1 with posterior decompression, and 1 patient with repeated tumor resection.

Clinical assessment was performed using the Frankel neurological grading system and Oswestry Disability Index before surgery and at the last follow-up. The patient satisfactory index was also obtained.

Surgical Procedure

We used the AO universal spine system pedicle screw (Synthes) in all surgeries because of its intensive correction ability. The patient was placed prone, and the operating table was adjusted to accommodate the kyphotic contour. General anesthesia was induced in each patient. During the operation, the blood pressure must remain normal to avoid restricted blood supply to the spinal cord. Autologous blood transfusion was also performed.

During the apical segmental resection osteotomy, subperiosteal stripping was carried out routinely to expose the posterior aspect of the spine, and pedicle screws were inserted 2 or 3 levels above and below the apical segment. A titanium rod was temporarily attached to the screws on one side to prevent shock or displacement during the osteotomy (Fig. 1A). A laminectomy was performed at the kyphotic segment. The transverse processes and/or articulating rib heads that were connected to the kyphotic apex were removed for about 3 cm to the side. The pleura and other soft tissues were then detached and stripped off from the lateral side to the anterior edge of the vertebrae. S-shaped retractors were used to protect the great vessels and anterior soft tissue. Care was taken to preserve the exiting nerve roots. Thus, the entire apical segment was exposed circumferentially. After the facet joints and pedicles were removed, the entire apical segment and the adjacent discs were resected while remaining attached to the posterior vertebral cortex and the posterior annular layers (eggshell technique). The anterior longitudinal ligament was exposed and severed. The temporary fixation rod was moved to the opposite side where the same procedure was repeated. Finally, the posterior vertebral cortex and annulus fibrosus were removed, and circumferential resection of the apical segment was completed (Fig. 1B). The number of vertebrae that needed to be resected depended primarily on the degree of correction required and how many vertebrae were fused. Care must be taken to protect the dural sac throughout the procedure.

During the dual axial rotation correction, a contoured titanium rod was connected to the cephalad pedicle screws. The pedicle screws were tightly held to avoid mismatching of osteotomies. The temporary fixation rod was gently removed. A distractor was carefully placed in the space between the adjacent nerve roots from behind, which allowed a distraction force to be applied slowly to the anterior osteotomy space. The distractor was held to maintain the space between the osteotomies, and fixation instruments and rod holders were used to press and rotate the proximal and distal spinal columns, respectively, simultaneously. After the proximal and distal osteotomies were rotated to be nearly parallel, the fixation rod was connected to the distal screws by reduction clamps. The other rod was fixed to obtain additional correction. During these correction maneuvers, the spinal cord must always be kept under direct vision to avoid unintended encroachment by the lamina or posterior cortices of the adjacent vertebrae. The flexed operating table was adjusted to normal contour during this step.

During reconstruction of the anterior column, the anterior space was distracted again to obtain further kyphotic correction. An artificial vertebra or titanium mesh packed with minced autograft bone (from the resected vertebrae and posterior element) was trimmed and placed into the anterior space between adjacent nerve roots from behind. Care should be taken not to compromise the spinal cord and nerve root during this step. Compression forces were applied to the pedicle screws to stabilize the
mesh and obtain more correction (Fig. 1C). Minced autograft bone was placed in the space around the implant. Care should be taken not to compress the spinal cord. The wound was closed over drainage in the usual fashion.

The entire osteotomy and correction process is illustrated in Fig. 2.

During the procedures, cortical SSEPs were monitored to evaluate spinal cord function. In 5 patients with abnormal cortical SSEPs during surgery, an intraoperative wake-up test was performed.

Postoperative Management

The drains were removed 2–3 days after surgery, and patients were allowed to ambulate wearing a brace 7 days after surgery. It was recommended that the patients wear the brace for 6 months postoperatively.

Results

All 23 patients underwent posterior apical segmental resection osteotomy with dual axial rotation correction as well as bone graft and artificial vertebrae (in 14 patients) or titanium mesh (in 9) implantation. The mean number of resected vertebrae was 2.7 (range 1–5). The mean duration of surgery was 6.7 hours (range 4.5–11 hours). The mean blood loss was 2960 ml (range 1000–5500 ml).

All patients were followed up for 2 or more years after surgery. The mean follow-up was 33.4 months (range 24–83.5 months). There were no intraoperative complications. The mean blood loss was 2960 ml (range 1000–5500 ml). The mean duration of surgery was 6.7 hours (range 4.5–11 hours).

Fig. 1. Photographs. A: The pedicle screw has been inserted, and temporary fixation is performed. B: Resection of the apical segment is finished. C: Dual axial rotation correction is achieved.

Fig. 2. Illustrations. A: The resection area of the posterior osteotomy. B: The resection area after apical segment resection osteotomy. C: The distractor is used to distract the space between the osteotomies, and fixation instruments and a rod presser are used to make correction of kyphosis, that is, dual axial rotation correction. The blue dots indicate the rotating axis of the osteotomies. D: The kyphosis is corrected and the anterior space is distracted. E: Titanium mesh packed with minced autograft bone is placed in the anterior space created by the resection osteotomy and distraction. Autograft bone is also implanted around the mesh.
Apical segmental resection osteotomy

24–60 months). All patients achieved a solid fusion except 1 patient who developed a pseudarthrosis and instrumentation failure 3 years after surgery and subsequently required a revision surgery. The corresponding fusion rate was 95.65%. The average kyphotic angle was corrected from 86.9° (range 50°–130°) before surgery to 25.6° (range –8° to 42°) immediately after surgery, making the average correction rate 72.17%. At the last follow-up, however, a slight loss of correction (1.8° on average) was noticed, giving an average kyphotic angle of 27.4° (range –7° to 44°), and the final average corrective rate of 69.87% (Figs. 3 and 4). The 9 patients with scoliosis had a mean coronal angle of 31.2° (range 12°–90°) preoperatively, which was corrected to 3.4° (range 0°–18°) immediately after surgery. The average correction rate was 90.06%. The average scoliosis angle was 4.8° (range 0°–24°) at the last follow-up, giving an average final correction rate of 83.39% (Table 1). Sagittal plane imbalance was present before surgery in 12 patients, including 9 patients with negative imbalance (average 52.9 mm) and 3 patients with positive imbalance (average 36.7 mm). At the last follow-up after surgery, 6 patients had a negative sagittal shift (mean 20.5 mm), which showed a significant improvement in sagittal plane balance; none had a positive imbalance. In some patients with a kyphotic angle greater than 90°, the aorta was initially circuitous in the kyphotic region, which was straightened after the correction. In 17 patients, their height was measured before and after the operation; the mean height gain was 6.2 cm (range 1–12 cm) after surgery.

At the last follow-up, all patients maintained or improved their neurological status. The preoperative Frankel grade was E in 8 patients, D in 8, C in 6, and B in 1 patient. At follow-up, Grade B improved to Grade C in 1 patient, Grade C improved to Grade D in 3 patients, Grade D improved to Grade E in 1 patient, and Grade D improved to Grade E in 6 patients. No patient lost function. In total, there were 15 cases of Grade E, 5 cases of Grade D, and 3 cases of Grade C. The average Oswestry Disability Index was 15.26 preoperatively (range 0–37) and 8.65 at follow-up (range 0–30). The average improvement rate was 43.30% (range 0%–100%). The patient satisfaction index showed that 15 patients were completely satisfied and 6 were partially satisfied with their outcome. The total satisfaction rate was 91.30%.

No patient had iatrogenic spinal cord or major vessel injury. One patient had progressive leg numbness and weakness due to backward displacement of the expandable artificial vertebra into the canal, compressing the spinal cord 3 days after surgery, and this was later relieved surgically. The artificial vertebra was a bit shorter than the osteotomy space in the revision surgery. Four patients had thoracic nerve root injury (T-6, T-7, T-8, and T-12), which led to transient trunk numbness. One patient suffered a left L-1 nerve root injury and resulting left iliopsoas weakness, which recovered after 1 month. The wake-up test was not performed in this patient during surgery. There were 3 cases of iatrogenic dural tears, which were repaired during surgery. One patient treated for congenital thoracic kyphosis sustained a major blood loss (about 5500 ml) and an approximately 75% decrease in the SSEP amplitude during the surgery. During the wake-up test, the movement of his feet was faint. The patient experienced transient aggravation of neurological deficits due to bilateral leg weakness (Grade C preoperatively) to frank paralysis (postoperatively), and yet his function recovered gradually to his preoperative level 1 month after surgery.

Discussion

The distraction of an anterior osteotomy site should be performed with reference to the tension of the spinal cord. If it is overstretched during distraction, the spinal cord as well as major anterior vessels could be damaged. On the other hand, insufficient distraction may result in over-shortening or overcrowding of the spinal cord. During the process of correction, the adjacent osteotomy segments should be held in line to prevent mismatching or torsion between the 2 segments.

There are several surgical approaches for correcting kyphotic deformities depending on the location and degree of deformity. Posterior closing wedge osteotomy has become the most widely used and is the best developed technique. Concern about potential over-shortening of the spinal cord and neurological injury during the osteotomy closure has led many authors to restrict the use of this technique to cases of thoracic/thoracolumbar kyphosis less than 40°. Shimode et al. used this technique and obtained an average 56.5° of correction without neurological injuries. However, there were only 7 patients in their series, and most were left with severe residual kyphotic deformity after the surgery.

Several problems have been encountered when posterior closing osteotomies alone were used to correct severe focal kyphosis. All cases of severe focal local kyphosis have prominent apices and overlapping ribs, which hinder the closing correction after osteotomy. Resection of multiple vertebrae may be necessary for the correction of the most severe kyphosis, in which closing of the osteotomies is highly likely to cause over-shortening, redundancy of the spinal cord, and potential neurological injury. Closing the posterior osteotomy after resection of multiple vertebrae can lead to mismatching of the cephalad and caudal osteotomies during the procedure, which can affect fusion of the bone graft. Directly closing the space left after the osteotomy may reduce the size of the thoracic or abdominal cavity, affecting the patient’s breathing capacity accordingly.

In 2001, Kawahara et al. introduced a new technique, known as the closing-opening wedge osteotomy, which maintained the height of the anterior column to lessen the likelihood of spinal cord over-shortening during the correction. Although the obtained correction rate was as high as 73%, only 7 cases were included in the study, and the average kyphotic angle was only 67° (the largest curve was 95°). The majority of their cases were posttraumatic kyphosis, and the kyphotic apex involved only 1 vertebra in all cases. We believe that their correction was still limited somewhat due to the preservation of the anterior longitudinal ligament. Moreover, closure of the posterior area was performed followed by opening of the anterior space during the corrective maneuver, which tended to minimize the space left by the osteotomy, and...
hence limited the correction rate. In some cases of severe kyphosis, especially kyphosis greater than 90°, the apex of deformity often includes more than 1 vertebral body, and the technique mentioned above may not get the same good results. In the patients in our study with more severe kyphosis, the new surgical correction technique achieved an average correction rate of 72.17%. The sagittal plane balance attained significant improvement. All but 1 of the patients achieved a good arthrodesis.

It is our belief that the proposed technique improves correction efficiency and safety for several reasons. Since the kyphotic apex is prominent posteriorly, the spinal cord and the local vertebral bodies are under direct vision from the lateral side, which allows us to resect not only the apical segment but also the anterior longitudinal ligament via a posterior approach. The entire apical segment, regardless of how many vertebrae it contains, has been resected together with the upper and lower disc, which provides enough space to correct the deformity and reconstruct the anterior column. Meanwhile, the overlapped ribs within the apex are resected at the same time to further increase correction. During the procedure, correction is achieved under controlled distraction of the anterior osteotomy space, and the surfaces of opposite osteotomies are not in contact. The correction maneuver is given more freedom and less restriction. When we distract the anterior osteotomy space and connect a rod to the cephalad and caudal screws, the opposite osteotomies rotate at the same time. With this technique, the spinal cord will not be over-shortened or redundant, and it will not be tightened by distraction force, which reduces the risk of neurological injury. Controlled distraction can avoid distortion of major anterior vessels as well as other injury to them. Anterior distraction, while holding tightly to the proximal and distal segments, can effectively prevent the dislocation or torsion of the osteotomy region. Implantation of artificial vertebrae or titanium mesh into the osteotomy space solves the problem of mismatching between the proximal and distal segments. In doing so, it affords the implanted segment a smoothly physiological contour. Noticeably, when used in the thoracic region, it can also help to preserve the volume of the thoracic cavity. An anterior column reconstruction under distraction force can lead to further kyphosis correction with sufficient bone graft.

Whether the resection of multiple vertebrae affects the blood supply of the spinal cord remains unknown. In the current series, 5 patients underwent resection of 4 vertebrae and 2 patients underwent resection of 5 vertebrae. Only 1 patient had abnormal SSEPs due to blood loss and low blood pressure during the apical resection; this patient presented with transient bilateral leg weakness after

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**Fig. 3.** Images obtained in a 17-year-old girl with tuberculous kyphosis of T10–L1.  
A: The kyphotic angle was 130° before surgery.  
B: Posterior segmental resection osteotomy with T6–L4 instrumentation and fusion. The Cobb angle improved to 37°.  
C: The correction was maintained 28 months after surgery.  
D: Complete fusion is seen on CT scanning 28 months after surgery.  
E: Preoperative photograph of the patient, showing severe kyphosis.  
F: Postoperative photograph showing cosmetic improvement.
Apical segmental resection osteotomy

surgery. Our hypothesis is that in patients with severe deformity, such as old tuberculosis or congenital kyphosis, the segmental vessels of the apical region were already destroyed or are dysfunctional, as the blood supply to the spinal cord comes from surrounding vessels. For these patients, resection of several deformed vertebrae should hardly interfere with blood supply to the spinal cord. Nevertheless, our experience indicates that maintaining appropriate blood pressure is the key to avoiding a loss of blood supply to the spinal cord, which can be evaluated using SSEP monitoring during apical segment resection.

In cases of severe focal kyphosis, such as tuberculosis, congenital deformity, or revision surgery, involved nerve roots tend to congregate tightly and become indistinguishable, increasing the risk of nerve root injury during surgery. In some studies, thoracic nerve roots were selectively cut during osteotomy, without causing significant complications. One of our previous patients had bilateral multiple nerve root injury during closing of the osteotomy correction procedure and developed a constricted feeling in the chest that lasted a while after surgery. In addition, 3 patients suffered a unilateral thoracic nerve root injury without major discomfort. In this study, special care was taken not to damage bilateral thoracic nerve roots simultaneously. Protection of nerve roots is of paramount importance in the lumbar spine where each nerve root plays a significant role in lower-extremity function. To protect the nerve root, extra attention should be paid during the resection of facet joints, stripping of the lateral vertebral aspect, insertion of the distractor, and implantation of titanium mesh. Sometimes the mesh cannot be inserted directly into the anterior space because of its length. Careful patient manipulation should be performed to insert the mesh vertically between the adjacent nerve roots, and then it should be rotated into the correct position in the anterior space.

The extent of correction is another concern that depends on the region of deformity. The fixation rod should be bent according to the physiological contour of the spine. In the thoracic region, the physiological kyphosis should be followed, and the thoracic spinal cord is even more fragile. Excessive correction should be avoided to maintain the normal regional contour and protect the spinal cord from injury. In the thoracolumbar segment,
however, the physiological contour is nearly 0°, and the spinal cord has more endurance, so more correction can be achieved in this area than in the upper region.

In this study, the range of fixation mostly spans 2 or 3 levels above and below the abnormal segment, as described in the literature.13,15 Our experience indicates that for traumatic kyphosis with less curvature, fixation of 2 levels above and below the apex should be enough. Nevertheless, for kyphosis due to TB or congenital kyphosis as well as some kyphosis caused by osteoporotic fracture, because of greater curvature and/or the poor quality of the bone, fixation of at least 3 levels above and below the apex are needed to maintain the correction.

Bone grafting and anterior column reconstruction are very important after correction and fixation. We use artificial vertebrae or titanium mesh to maintain the space created by apical resection and distraction, which can also prevent compression and overcrowding of the spinal cord. The removed bone is minced and reused to fill the mesh and the excavated space, which is then covered with layers of sponge gel to conceal the spinal canal. Interlaminar bone grafting is also performed at the levels above and below the region of kyphosis correction. This method is shown to lead to solid arthrodesis at follow-up.

This study may be criticized since we did not use motor evoked potential monitoring to evaluate changes in spinal cord function during surgery as it was not available. Should motor evoked potential monitoring become available to us, we will use it along with SSEP monitoring to improve evaluation of spinal cord function.

To the best of our knowledge, apical segmental resection osteotomy with dual axial rotation distraction correction and instrumented fusion as described in this study is an effective and safe technique for the treatment of severe focal kyphosis. Nevertheless, considering the risks of the extended surgical time, potentially heavy blood loss, and possible neurological injury involved, the indications for this type of surgery should be carefully discussed, and the surgical team needs to be highly experienced in this regard.

**Conclusions**

Apical segmental resection osteotomy with dual axial rotation correction and instrumented fusion is an effective and safe way to treat severe focal kyphosis.

**Disclosure**

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

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**TABLE 1: Kyphosis correction rate in 23 patients**

<table>
<thead>
<tr>
<th>Case No.</th>
<th>Diagnosis</th>
<th>Preop (°)</th>
<th>Postop (°)</th>
<th>Postop Correction Rate (%)</th>
<th>Final FU (°)</th>
<th>Final FU Correction Rate (%)</th>
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<tr>
<td>1 old fracture</td>
<td>50</td>
<td>–8</td>
<td>116.00</td>
<td>–7</td>
<td>114.00</td>
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<tr>
<td>2 congenital</td>
<td>94</td>
<td>42</td>
<td>55.30</td>
<td>43</td>
<td>54.30</td>
<td></td>
</tr>
<tr>
<td>3 TB</td>
<td>100</td>
<td>30</td>
<td>70.00</td>
<td>30</td>
<td>70.00</td>
<td></td>
</tr>
<tr>
<td>4 congenital</td>
<td>54</td>
<td>–4</td>
<td>107.40</td>
<td>–2</td>
<td>103.70</td>
<td></td>
</tr>
<tr>
<td>5 old fracture</td>
<td>90</td>
<td>31</td>
<td>65.60</td>
<td>43</td>
<td>52.20</td>
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</tr>
<tr>
<td>6 TB</td>
<td>118</td>
<td>37</td>
<td>68.60</td>
<td>37</td>
<td>68.60</td>
<td></td>
</tr>
<tr>
<td>7 TB</td>
<td>109</td>
<td>32</td>
<td>70.60</td>
<td>32</td>
<td>70.60</td>
<td></td>
</tr>
<tr>
<td>8 congenital</td>
<td>78</td>
<td>35</td>
<td>55.10</td>
<td>35</td>
<td>55.10</td>
<td></td>
</tr>
<tr>
<td>9 TB</td>
<td>115</td>
<td>42</td>
<td>63.50</td>
<td>44</td>
<td>61.70</td>
<td></td>
</tr>
<tr>
<td>10 TB</td>
<td>92</td>
<td>20</td>
<td>78.30</td>
<td>25</td>
<td>72.80</td>
<td></td>
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<tr>
<td>11 congenital</td>
<td>61</td>
<td>20</td>
<td>67.20</td>
<td>24</td>
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<tr>
<td>12 TB</td>
<td>98</td>
<td>30</td>
<td>69.40</td>
<td>30</td>
<td>69.40</td>
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<tr>
<td>13 congenital</td>
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<td>33</td>
<td>69.70</td>
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<tr>
<td>14 TB</td>
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<td>15 postop osteoblastoma</td>
<td>89</td>
<td>36</td>
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<td>39</td>
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<td>16 congenital</td>
<td>65</td>
<td>19</td>
<td>70.80</td>
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<tr>
<td>17 TB</td>
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<td>30</td>
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</tr>
<tr>
<td>22 congenital</td>
<td>103</td>
<td>30</td>
<td>70.87</td>
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<td>70.87</td>
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<td>23 TB</td>
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<td>58.90</td>
<td>30</td>
<td>58.90</td>
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* FU = follow-up; TB = tuberculosis.
Apical segmental resection osteotomy

Author contributions to the study and manuscript preparation include the following. Conception and design: Chen. Acquisition of data: all authors. Analysis and interpretation of data: Zeng. Drafting the article: Zeng, Li. Critically revising the article: Zeng. Reviewed final version of the manuscript and approved it for submission: all authors. Statistical analysis: Zeng. Study supervision: Chen.

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