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ORIGINAL ARTICLE / *ORJİNAL MAKALE*

TOTAL WEDGE RESECTION OSTEOTOMY (DOMANIC OSTEOTOMY) FOR SURGICAL CORRECTION OF RIGID AND ANGULAR SPINAL DEFORMITIES

İLERİ DERECE VE RİJİD OMURGA DEFORMİTELERİNDE TOTAL KAMA REZEKSİYON (DOMANİÇ) OSTEOTOMİSİ

Ünsal DOMANİÇ*, Fatih DİKİCİ, Turgut AKGÜL***, Cüneyt ŞAR*, Ufuk TALU*, Azmi HAMZAOĞLU******

SUMMARY:

Introduction: Anterior and posterior procedures are usually combined for the surgical treatment of severe, rigid and local kyphosis secondary to trauma, infection, congenital anomalies or failed surgeries. This study presents our technique, clinical and radiologic results with posterior total wedge resection osteotomy which is a one-stage solution resulting in shortened posterior column and decreased tension on spinal cord in rigid angular deformities.

Patients and Methods: Between 1990 and 2010, 61 patients with rigid angular spinal deformities were surgically treated by posterior total wedge resection osteotomy and instrumentation. Etiology was congenital malformation in 37, infection in 13, ankylosing spondylitis in three, and previous laminectomy in eight patients. The osteotomy was performed at the apex of the deformity and covered two vertebrae. Upper and lower border of the osteotomy are right inferior to the transverse processes of the upper and lower vertebrae respectively. Apex of the posteriorly based triangular osteotomy is either at the anterior vertebral body or anterior longitudinal ligament.

Results: The mean preoperative angle of local kyphosis for thoracal and thoracolumbar region was 67o (25o-112o) and it improved to a mean of 220 (00-480) after an average follow-up of 109 (12-192) months. The mean preoperative angle of local kyphosis in lumbar region was 100 ((-430)-700) and it improved to a mean of -120 ((-330)-220). The mean loss of correction since operation was 2.80 (00-110). Radiologically solid anterior and posterior fusion was achieved in all patients by six months. One (1.6 %) patient had irreversible paraplegia postoperatively.

Conclusion: Posterior total wedge resection osteotomy eliminates the need for anterior procedure. Posterior column shortening decrease potential neurologic deficit risk by eliminating tractional force on spinal cord. It is an effective one-stage procedure especially for the treatment of sharp and rigid angular spinal deformities.

Keywords: *Spinal deformity, total wedge resection, osteotomy*

Level of evidence: *Retrospective clinical study, Level III*

(*) Prof. Dr., Orthopaedic Surgeon, Istanbul University, Istanbul Medical Faculty, Department of Orthopaedics and Traumatology, İstanbul.
(**) Orthopaedic Surgeon, Istanbul University, Istanbul Medical Faculty, Department of Orthopaedics and Traumatology, İstanbul
(***) Resident, Istanbul University, Istanbul Medical Faculty, Department of Orthopaedics and Traumatology, İstanbul.
(****) Prof. Dr., Orthopaedic Surgeon, Florence Nightingale Hospital, Istanbul.

İletişim Adresi: *Op. Dr. Fatih Dikici*
İstanbul Üniversitesi İstanbul Tıp Fakültesi Ortopedi ve Travmatoloji Anabilim Dalı
Millet cad. 34093, Fatih İstanbul
Tel.: *212 4142000-31511*
e-mail: *fatihdikici71@hotmail.com*
GSM: *532 2477135*

ÖZET:

Giriş: Omurganın, bölgesel kifozun da eşlik ettiği, ileri dereceli, açısal, sert deformiteleri, travmalar, geçirilmiş enfeksiyonlar, konjenital anomaliler ve başarısız bel cerrahileri sonrasında görülebilir. Bu tür omurga deformitelerinin tedavisinde anterior ve posterior cerrahiler kombine şekilde uygulanmaktadır. Çalışmamızda omurganın posterior kolonunu kısaltıp, omurilikteki gerilme kuvvetini azaltan, deformitenin düzeltilmesinde tek aşamalı çözüm sunan, teorik olarak nörolojik hasar riskini en aza indiren, omurganın total kama rezeksiyon osteotomisi tekniğimizi sunulmaktadır.

Hastalar ve Yöntem: 1990-2010 yılları arasında rijid, ileri derecede açısal omurga deformitesi bulunan 61 hasta posterior total kama rezeksiyon osteotomisi yapılarak tedavi edildi. Çalışmaya alınan hastaların etyolojileri, 37 konjenital, 13 infeksiyon, 8 daha önceden yapılan laminektomiler ve 3 ankilozan spondilit olarak belirlendi. Osteotomiler, iki vertebrayı kapsayacak şekilde, deformitenin tepe noktasından yapıldı. Osteotominin sınırları her iki omurun transvers çıkıntılarının hemen altından geçecek şekilde yapıldı. Tabanı posteriorda olacak şekilde çıkarılan üçgen kamanın tepe noktası omur cisminin ön yüzü veya anterior longitudinal ligaman olarak belirlendi.

Bulgular: Operasyon öncesi ortalama lokal kifoz açısı, torakal ve torakolomber bölgede 67˚ (25˚-112˚) olarak hesaplandı. Operasyon sonrası ortalama 109 (12-192) ay takip edilen hastalarda bu değer 220˚ (0˚-48˚) olarak ölçüldü. Operasyon öncesi ortalama lokal kifoz açısı, lomber bölgede 10˚ ((-43˚)-70˚) olarak hesaplandı. Bu değerin hastaların son takiplerinde -12˚ ((-33˚)-22˚)'ye gerilediği görüldü. Operasyondan sonrası son kontrollerde görülen korreksiyon kaybı ise ortalama 2.8˚ (0˚-11˚) olarak hesaplandı. Hastalarda tümünde 6. ayın sonunda radyolojik olarak anterior ve posterior solid füzyon sağlanmış olduğu izlendi. Bir hastada (% 1.6) operasyon sonrası geri dönüşümsüz parapleji saptandı.

Sonuçlar: Omurganın posterior kama rezeksiyon osteotomisi, anterior girişime ihtiyaç kalmadan, deformitenin tam düzeltilebilmesine olanak tanır. Posterior kolon kısalması, medulla spinaliste risk oluşturabilecek traksiyon güçlerine engel olduğundan hastadaki nörolojik araz riski en aza inmektedir. Tek aşamalı bu yöntem, özelikle yüksek açılı ve rijid omurga deformitelerinde etkili ve başarılı bir yöntemdir.

Anahtar Kelimeler: *İleri omurga deformitesi, total kama rezeksiyonu, osteotomi*

Kanıt Düzeyi: *Retrospektif klinik çalışma, Düzey III*

INTRODUCTION:

Severe angular kyphosis or kyphoscoliosis may develop secondary to a fracture, an infectious process, laminectomy and congenital malformations. Independent of the etiology severe, rigid and localized kyphosis usually requires surgical treatment in order to prevent progressive deterioration of the sagittal imbalance and neurologic function. Many different anterior, posterior or combined procedures were developed and reported by various authors [1,6-7,10-11,14-16,20].

There are many authors who have tried and succesfully performed corrective osteotomy for severe spinal deformity using posterior approach. Such osteotomies bring the advantage of shortened posterior column and decreased tension on spinal cord with a single-stage procedure [1,3-5,9,12-13,17-19]. Original description was by Smith-Petersen in 1945, who performed a limited osteotomy involving only the posterior elements to correct the kyphotic deformity in ankylosing spondylitis [18]. Simmons also performed posterior osteotomy with a similar technique [17]. In 1984, Heinig has developed the posterior "egg-shell" procedure which involved transpedicular evacuation of a portion of the vertebral body followed by a controlled compression fracture [9]. This was followed by Thomasen in 1985, who described another variation in which the pedicles and small portion of the body were removed after Smith-Petersen osteotomy, thereby accomplishing a partial vertebral resection [19]. In 1992 Gertzbein reported his modification which combined the techniques of Heinig and Smith-Petersen, resulting in closing dorsal wedge osteotomy [4].

In 1994 Steffee presented a new technique that is a true-closing wedge posterior transvertebral osteotomy for the treatment of adult thoracolumbar kyphosis [10]. Domaniç et al presented their technique which was devised in 1990 for rigid angular kyphosis [3]. Tomita et al and Rajasekaran et al also presented their series with closing-opening wedge osteotomy by posterior approach [5,13].

PATIENTS AND METHODS:

61 patients with rigid and localized kyphotic deformities underwent surgical treatment consisting of posterior total wedge resection osteotomy and posterior instrumentation between January 1990 and February 2010 at our institution. There were 24 men and 37 women and their average age at the time of operation was 21 (7-42) years. Each patient had disabling pain and severe deformity. The etiology was congenital malformation in 37 (60 %), healed tuberculous infection in 13 (21 %), previous laminectomy in 8 (13 %) and ankylosing spondylitis in 3 (6 %) cases. None of the patients had preoperative neurologic deficit. The preoperative and postoperative local deformity was measured according to the Cobb method from the superior end-plate above the deformity and from the inferior end-plate below the deformity.

The osteotomy and wedge resection level was at T8-T9 in three patients, at T10-T11 in four patients, at T8-10 in one patient, at T12-L1 in 21 patients, at L1-L2 in 20 patients, at L2-L3 in six patients, at L3-L4 in five patients, at L4-5 in two patients and L5-S1 in one patient. Two patients had two osteotomies at levels of T8 and T10. Data of the patients is given in Table 1.

All patients had Stagnaras wake-up test at the end of the osteotomy and instrumentation, before the wound closure. All patients had intensive care unit monitoring and intravenous antibiotics for 48 hours. Urinary catheters and suction drains were usually removed before the last dose of antibiotics. Ambulation was usually begun on the

Table 1: Patient data

Case	Age	Sex	Diagnosis	Osteotomy level(s)	Preop local kyphosis angle	Postop local kyphosis angle	Follow up (month)
1	20	F	PL	T12-L1	25	5	107
2	11	M	CM	T10-11	85	35	186
3	13	M	CM	L2-3	70	0	110
4	10	F	CM	T12-L1	50	26	132
5	13	F	PI	T8-10	76	26	156
6	22	F	PL	T12-L1	80	20	114
7	36	M	PI	L2-3	40	0	115
8	22	F	CM	L1-2	40	15	128
9	25	M	PL	L1-2	45	10	134
10	18	F	CM	T12-L1	62	15	128
11	18	F	PI	T12-L1	55	10	180
12	17	M	CM	L1-2	90	40	188
13	12	M	CM	L1-2	78	32	172
14	26	F	PI	T12-L1	112	48	162
15	23	M	CM	L1-2	85	27	150
16	18	M	PI	T12-L1	105	46	168
17	15	F	CM	T12-L1	81	29	150
18	16	F	CM	L1-2	95	36	167
19	26	M	PI	L1-2	80	20	156
20	25	F	CM	T12-L1	92	33	164
21	13	F	PI	L2-3	75	27	164
22	18	M	PL	T12-L1	94	41	192
23	20	F	PI	L1-2	48	5	112
24	27	M	CM	L1-2	54	8	104
25	16	F	PI	L1-2	67	24	110
26	40	M	CM	L2-3	58	14	114
27	18	M	CM	T12-L1	86	24	108
28	13	M	CM	L1-2	66	29	124
29	11	M	CM	L1-2	74	23	122
30	21	M	PI	T12-L1	94	30	108
31	24	M	PI	L1-2	72	23	130
32	40	M	AS	L1-2	72	50	89
33	34	M	AS	L1-2	51	19	29
34	13	F	CM	T12-L1	89	23	100
35	30	F	CM	T12-L1	85	30	95
36	11	M	CM	T12-L1	64	23	93
37	11	F	CM	L1-2	63	14	27
38	40	F	CM	T12-L1	59	12	49
39	20	F	CM	T10-11	53	8	77
40	15	F	CM	T12-L1	32	4	89
41	11	F	CM	L1-2	90	6	111
42	6	F	CM	L1-2	53	40	81
43	13	F	CM	T8-9	33	19	59
44	18	F	CM	T8-9,T10-11	28	19	81
45	25	F	CM	T12-L1	95	11	79
46	7	F	CM	T12-L1	42	8	75
47	29	F	PI	T12-L1	70	28	71
48	23	F	PL	T10-11	44	14	90
49	14	F	PL	T12-L1	58	12	69
50	8	F	CM	L1-2	55	30	71
51	16	F	CM	L1-2	33	11	12
52	17	F	CM	L2-3	42	22	71
53	28	M	PL	L4-5	38	4	60
54	42	F	PL	L5-S1	50	19	64
55	7	F	CM	L3-4	-43	-27	90
56	16	F	CM	L3-4	-5	-25	112
57	34	F	CM	L3-4	-8	-36	76
58	11	F	CM	L4-5	-35	-28	73
59	35	M	CM	L2-3	-20	-33	96
60	34	M	PI	L3-4	70	18	153
61	35	M	AS	L3-4	6	-33	59

M: Male, F: Female, CM: Congenital malformation, PL: Postlaminectomy, PI: Postinfection

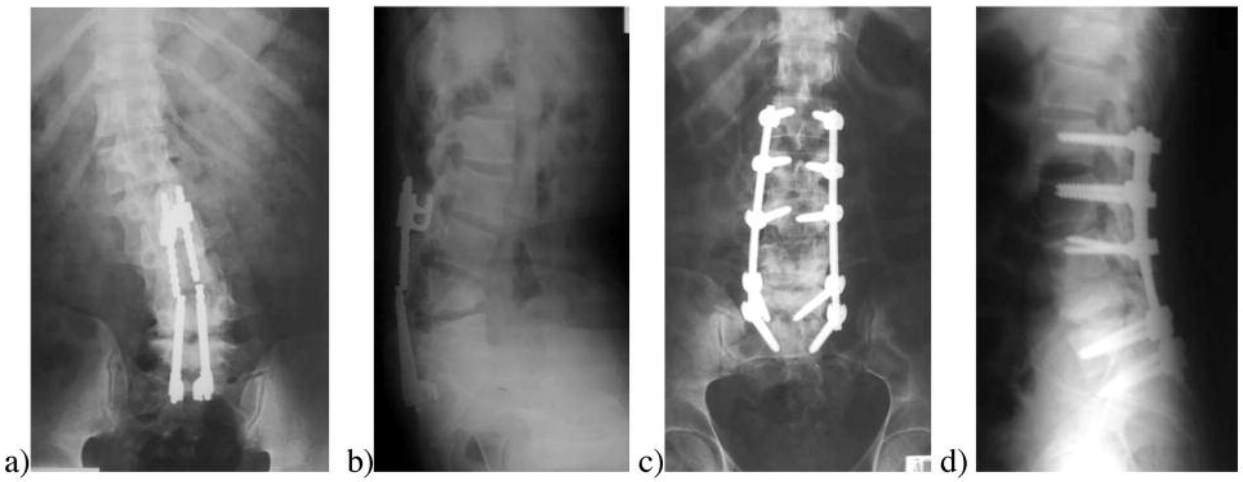

Figure-1. L4 posterior wedge osteotomy was performed in a 28 years old man with previous failed back surgery for L4 fracture. Preoperative radiographs show implant failure **(a)** and local kyphosis **(b)**. Postoperative radiographs show restored coronal **(c)** and sagittal **(d)** balances.

second or third postoperative day. Radiographs were taken immediately postoperatively and on the day of discharge. Follow-up radiographs were performed at 6 weeks and 3, 6 and 12 month intervals. Radiographic fusion was determined to be solid if there were bone bridging at the osteotomy site in anteroposterior, lateral and bilateral oblique projections.

Operative Technique:

The patient is placed in the prone position on chest rolls on the operating table. A single midline posterior longitudinal incision is used for exposing the area and levels that are determined before. Paraspinal muscles and all soft tissues are stripped subperiostally from the bone laterally to the tips of the transverse processes. An intraoperative radiograph with guide pins is obtained for accurate localization of the deformity and determining the level and extent of the osteotomy. A complete laminectomy and facetectomy is performed first at the posterior resection site and than lateral walls of the spinal canal are excised bilaterally. The spinal nerves are carefully dissected and preserved. The osteotomy is performed at the apex of the kyphotic deformity usually covering two vertebrae. Upper and lower border of the osteotomy are right inferior to the transverse processes of the upper and lower vertebrae respectively. Apex of the posteriorly based triangular osteotomy is planned to be either at the anterior vertebral body or anterior longitudinal ligament. The osteotomy is performed carefully to avoid overpenetration of the anterior cortex or anterior longitudinal ligament with the purpose to provide a hinge point to avoid translation and also to prevent injury to the major or radicular vessels. Once the osteotomy and wedge resection are completed the left portions of the upper and lower vertebrae usually form an intervertebral foramen containing two spinal nerves on both sides at the resection site. Facets to be included in the fusion area should be resected, screws and hooks should be placed and a previously bent rod should be loosely attached on one side before completing the osteotomy so that the step-off is avoided. Upon completion of the osteotomy a second rod is placed and both are equally compressed

so that correction and stabilization are achieved. In order to avoid dural buckling while closing the osteotomy site partial laminectomy should be performed one level above and one level below the osteotomy. Decortication and bone grafting should necessarily follow the instrumentation. Hypotensive anaesthesia and perioperative autotransfusion by means of cell-saver were used in all cases to reduce the need for homologous bank blood.

RESULTS:

The mean preoperative angle of local kyphosis was 67° (25°-112°) and it improved to a mean of 22° (0°-48°) at an average follow-up of 109 (12-192) months. The mean preoperative angle of local kyphosis in lumbar region was 10° ((-43°)-70°) and it improved to a mean of -12° ((-33°)-22°). The mean loss of correction since operation was 2.8° (0°-11°) and loss of correction was seen only within the first three months. Radiologically solid anterior and posterior fusion was achieved in all patients by six months.

As complications there were no fatal complications. However, the intraoperative wake-up test was positive in one patient (1,6 %) who was early in the series and developed irreversible paraplegia despite all efforts to prevent. Removal of instruments did not help and through exploration of the osteotomy site did not reveal any mechanical problem or pathology. Two patients had transient nerve root injury which recovered completely at six months. Two patients developed early deep infection which responded to early aggressive debridement without removal of the instruments. As minor complications dural tear occured intraoperatively in two patients. Repair was effective without any leak. Implant failure occured in two patients as hook pull-out which was noted at 3 months. One was revised and the other one was not reoperated as it caused no mechanical problem or irritation. There were no implant related complication.

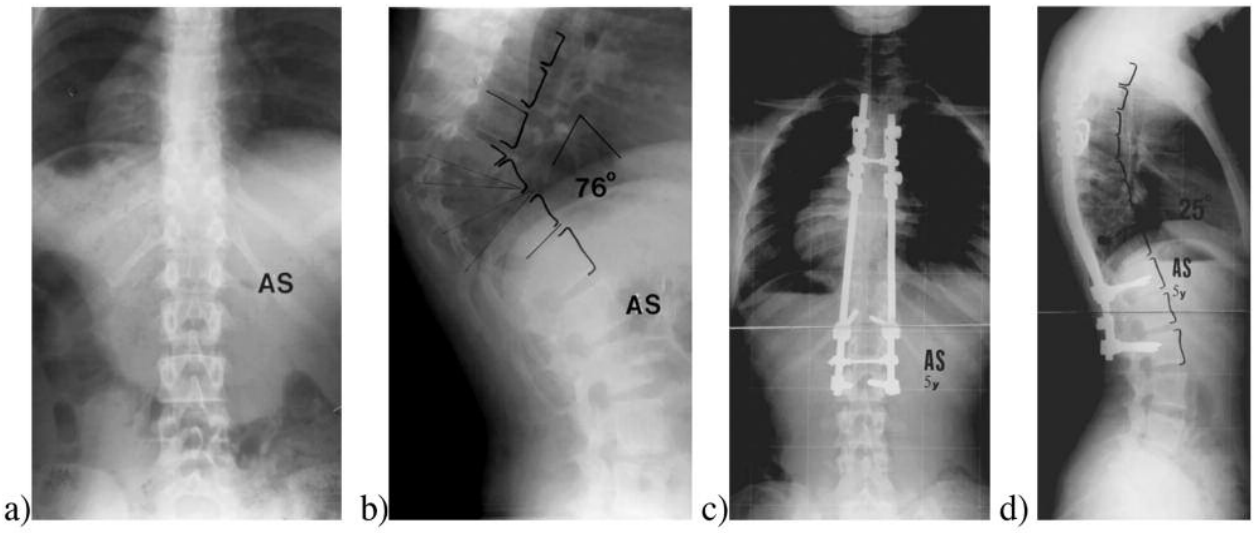

Figure-2. T8-10 posterior wedge osteototomy was performed in a 13 years old female with postinfectious thoracal rigid angular deformity. Preoperative radiographs show local severe kyphosis (a,b). Five years follow-up radiographs show full bony union with restored sagittal balance (c,d).

DISCUSSION:

There is a wealth of literature on surgical techniques to correct thoracolumbar kyphosis mainly due to ankylosing spondylitis or congenital hemivertebrae. The pathogenesis of angular kyphosis however in general involves either destruction (fracture, infection, tumor or laminectomy) or localized congenital malformation. White et al reported biomechanical consequences of kyphotic deformity [21]. Short-curved kyphosis moves the center of gravity further anteriorly and this results in a viscious cycle of increasing deformity and segmental instability. The results of increasing wedging and deformity are pain and neurological deficit [3,5,13,21]. All these pathologies require surgical interventions.

Combined anterior and posterior procedures are commonly used for treatment of such angular and rigid kyphosis. Anterior and posterior surgery can be done in different stages as same-day surgery or simultaneously [1,6,14]. Combined procedure may cause increased blood loss, operating time and increased patient morbidity especially in the aged population [9,15]. Patients with severe kyphosis may also suffer from respiratory dysfunction and anterior surgery may inevitably further deteriorate the respiratory functions. Also anterior surgery in patients with a very sharp and rigid kyphotic segment may be technically very difficult and removal of the whole deformed bone with posterior longitudinal ligament and decompression may involve the risk of direct neural tissue injury since there is usually no space available between the bone and the spinal cord itself [3,5,13].

Single-stage posterior approach may be of more benefit with lower morbidity in the older population and in patients with respiratory problems. Leatherman et al stressed that the only surgical method that can be used for the correction of spinal deformity without risk of neurological problem is shortening of the spine [5,8]. Another advantage of a one-stage posterior closing wedge resection osteotomy is that it results in shortened posterior column and decreased tension on spinal cord. As some authors pointed out as well, closing wedge resection osteotomy provides biomechanically superior construct in correction of kyphotic deformity by placing the fulcrum anteriorly and by not opening up but providing bone-to-bone contact in the anterior column [3-5,9,13]. On the other hand, closing total wedge resection osteotomy has some drawbacks as well. Spinal shortening procedure and dural buckling can result from closure of the osteotomy. This limits our correction to a maximum of 60°. Heinig reported their correction degree as 40° or 50°, and Gertzbein reported this limit as 40° without neurological deficit [4,9]. Steffee recommends duraplasty while closing the osteotomy to prevent dural buckling in patients where the correction was more than 35° [9]. Tomita et al reported correction degree as 49° (range, 33°-61°) with translation [5]. The mean correction angle was 45° for our patients. Dural buckling is a problem but in our experience, it rarely disturbs the dural pulsation or cerebrospinal fluid mechanics. As a preventive measure we always perform a wide laminectomy one level above and below the osteotomy site and this relieves the tension on spinal cord.

If one needs more correction, the solution would be a second osteotomy depending on the deformity. Or if there is a big residual kyphosis despite the osteotomy, one may prefer to add anterior strut-graft to avoide the risks of pseudoarthrosis or implant failure. Another option for more correction would be careful disruption of the anterior hinge (either bone or ligament) or total vertebrectomy to open-up the anterior column but this gap should then be

reconstructed with a strut graft or preferably with a titanium mesh cage placed via posterior approach as well. Another but surgically more traumatic approach would be the three-stage (posterior and then anteroposterior) surgery in a young and fit patient [15].

Posterior total wedge resection osteotomy is nevertheless a high risk procedure for neurologic complications requiring experience and overcaution. In our series we had one major (irreversible paraplegia) and two minor (transient nerve root dysfunction) neurologic complications (total 5%). This is similar to Steffee's complication rate in his series [9]. Suk et al reported their complications as one complete cord injury and two root injuries of 25 patients [16]. Dalvie et al reported one neurologic complication in a series of nine patients [2]. The possible etiology of these cord lesions could be direct injury to the spinal cord, dural compression, impaired vascular supply or spinal canal malalignment. Our major complication of irreversible paraplegia developed in one of our initial patients in the series and it was most probably due to ischemia since there was no direct neural tissue injury or mechanical problem.

Area of fusion and length of instrumentation depends on the amount and flexibility of the compensatory sagittal and/or frontal plane deformity. New generation strong instrumentation systems especially segmental pedicle screw constructs provide powerful correction and adequate stability as long as sagittal balance is restored. Steffee preferred short segment fusion and instrumentation but reported high rate of pain and additional procedures [9]. This may be related to degeneration and pain on adjacent non-instrumented segments. We did not experience postoperative pain or adjacent segment problems in our patients and we attribute this to the long segment of fusion and instrumentation in the initial group of 20 patients. The latter group of 41 patients have shorter areas of fusion and instrumentation and they also have no complaints.

Total wedge resection osteotomy brings a good and effective one-stage solution to the challenging clinical problem of rigid localized kyphosis due to various acquired or congenital etiologies.

REFERENCES:

1. Bridwell KH**.** Osteotomies for fixed deformities in the thoracic and lumbar spine. In: The textbook of spinal surgery (2nd edition) (Ed. Bridwell KH and DeWald RL). Lippincott-Raven. Philadelphia 1997; 821-835.
2. Dalvie SS, Laheri VJ. Closed-wedge spinal osteotomy for the correction of post-tubercular kyphosis in children. *J Bone Joint Surg (Br)* 2000; 82: 283-284.
3. Domanic U, Talu U, Dikici F, Hamzaoglu A. Surgical correction of kyphosis: posterior total wedge resection osteotomy in 32 patients. *Acta Orthop Scand* 2004; 75: 449-455.
4. Gertzbein SD, Harris MB. Wedge osteotomy for the correction of post- traumatic kyphosis. *Spine* 1992; 17: 374-379.
5. Kawahara N, Tomita K, Baba H, Kobayashi T, Fujita T, Murakami H. Closing-opening wedge osteotomy to correct angular kyphotic deformity by a single posterior approach. *Spine* 2001; 26: 391-402.
6. Kostuik JP, Maurais GR, Richardson WJ, Okajima Y. Combined single stage anterior and posterior osteotomy for correction of iatrogenic lumbar kyphosis. *Spine* 1988; 13: 257-266.
7. La Chapelle EH. Osteotomy of the lumbar spine for correction of kyphosis in a case of ankylosing spondylarthritis. *J Bone Joint Surg (Am)* 1946; 28: 851-858.
8. Leatherman KD, Dickson RA. Two-stage corrective surgery for congenital deformities of the spine. *J Bone Joint Surg [Br]* 1979; 61: 324-328.

9. Lehmer SM, Keppler L, Biscup RS, Enker P, Miller SD, Steffee AD. Posterior transvertebral osteotomy for adult thoracolumbar kyphosis. *Spine 1*994; 18: 2060-2067.
10. Malcolm BW, Bradford DS, Winter RB, Chou SN. Post-traumatic kyphosis: A review of forty-eight surgically treated patients. *J Bone Joint Surg (Am) 1*981; 63: 891-900.
11. McAfee PC, Bohlman HH, Yuan HA. Anterior decompression of traumatic thoracolumbar fractures with incomplete neurological deficit using a retroperitoneal approach. *J Bone Joint Surg (Am)* 1985; 67: 89-104.
12. McMaster PE. Osteotomy of the spine for fixed flexion deformity. *J Bone Joint Surg (Am)* 1962; 44: 1207-1216.
13. Rajasekaran S, Vijay K, Shetty PA. Single-stage closing-opening wedge osteotomy of spine to correct severe post-tubercular kyphotic deformities of the spine: a 3-year follow-up of 17 patients. *Eur Spine J* 2010; 19: 583-592.
14. Robertson JR, Whitesides THE. Surgical reconstruction of late posttraumatic thoracolumbar kyphosis. *Spine* 1985; 10: 307-312.
15. Sar C, Eralp L. Three-stage surgery in the management of severe rigid angular kyphosis. *Eur Spine J* 2002; 11: 107-114.
16. Se-Il Suk, Kim JH, Kim WJ. Posterior vertebra column resection for severe spinal deformities. *Spine* 2002; 27: 2374-2382.
17. Simmons EH. Kyphotic deformity of the spine in ankylosing spondylitis. *Clin Orthop* 1977; 128: 65-77.
18. Smith-Petersen MN, Larson CB, Aufranc OE. Osteotomy of the spine for correction of flexion deformity in rheumatoid arthritis. *J Bone Joint Surg (Am)* 1945; 27: 1-11.
19. Thomasen E. Vertebral osteotomy for correction of kyphosis in ankylosing spondylitis. *Clin Orthop 19*85; 194: 142-152.
20. Weidenbaum M, Farcy JPC. Surgical management of thoracic and lumbar burst fractures. In: The textbook of spinal surgery (2nd edition) (Ed. Bridwell KH and DeWald RL). Lippincott-Raven, Philadelphia 1997; 1839-1880.
21. White AA III, Panjabi MM. Practical biomechanics of scoliosis and kyphosis: Clinical biomechanics of the spine. 2nd ed. Philadelphia: JB Lippincott, 1990; 127-168.