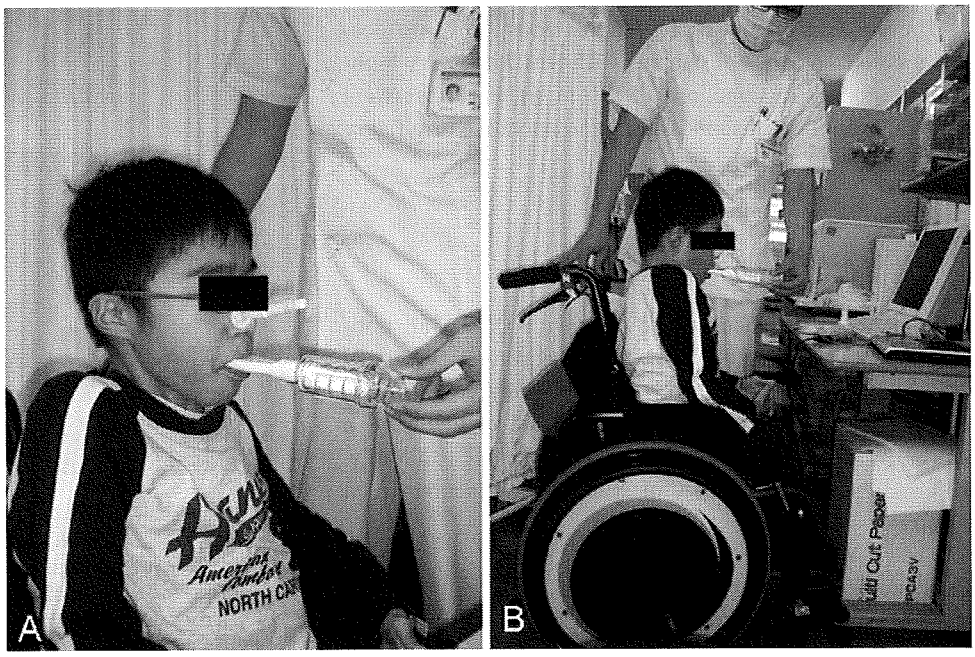

Fig. 2 a,b A 12-year-old boy with Duchenne muscular dystrophy (DMD) being trained to use the Threshold IMT in a sitting position

Results

Details of all the patients are shown in Table 2. Changes in FVC are shown in Fig. 3. The mean FVC at the time of admission was 21.6% (range, 16–27%). There were no ventilator dependent patients preoperatively. FVC increased in all patients at three weeks before operation to 24.1% (range, 19%–28%). FVC increased to 26.2% (range, 22–31%) the day before operation. The mean preoperative scoliotic curvature was 98° (range, 81°–130°). All patients had posterior spine fusion and all-screw construction from the upper thoracic spine (T3 or T4) to the lower lumber spine (L5) for scoliosis. No anterior surgery was performed in any of this consecutive series. All patients were extubated on the day of opreration in spite of poor preoperative pulmonary function. Frequent aspiration of debris was performed by nurses in the immediate postoperative period. No patients showed abnormal pulse oximetry monitoring values in the immediate postoperative period. No patients developed any respiratory complications such as postoperative pneumonia or required reintubation or tracheotomy. The postoperative scoliotic curvature was 34° (range, 20°–40°) (65%). FVC increased very slightly or remained stable in all patients at six weeks after operation. Although there was very slight increase in FVC of six patients after operation, there was no significant difference in

Table 1 Six-week preoperative IMT exercise training protocol

Subject's baseline MIP pressure: <50cm H_2O				
Borg RPE	<13	13–15	>15	>17
Pressure resistance (cm H_2O)	Increased by 2	Increased by 1	Maintained at same level	Reduced by 2
Subject's baseline MIP pressure: <50 cm H_2O				
Borg RPE	<13	13–15	>15	>17
Pressure resistance (cm H_2O)	Increased by 4	Increased by 2	Maintained at same level	Reduced by 2
If subject developed symptoms (i.e. dizziness, lightheadedness, or shortness of breath) while performing IMT exercise, the resistance was adjusted as follows until no symptoms persisted				
Symptoms	Two or more symptomatic episodes in a row per week		1–2 isolated symptomatic episodes per week	
Pressure resistance (cm H_2O)	Decreased by 2. Subjects were called back 3 days later to monitor subject's response		Held constant, subjects were called back three days later to monitor subject's response	

IMT inspiratory muscle strength training, *MIP* maximal inspiratory pressure, *RPE* rating of perceived exertion

IMT exercises were performed daily for ten weeks with three sets of 15 repetitions. If a subject achieved the maximum IMT trainer pressure resistance of 41 cm H_2O and resistance could no longer be increased, a fourth set of exercises was added with an increased number of repetitions up to a maximum of 15 repetitions. Initial resistance (H_2O cm) of the IMT was set at 30% of the subjects pretest MIP. Subjects were called once per week by one of the investigators to assist with IMT pressure resistance training progression. IMT pressure resistance was increased weekly according to the subject's symptoms

Table 2 Details of the patients and operative details

Patient no.	Age (y)	Six weeks before operation	The day before operation		Immediately after operation		Two years after operation		Operative time (min)	Intraoperative blood loss (ml)	Complications
		FVC(%)	Scoliotic curvature (°)	FVC(%)	Scoliotic curvature (°)	FVC(%)	Scoliotic curvature (°)	FVC(%)			
1	11	23	100	28	38	29	40	19	249	889	Tachycardia
2	12	22	93	27	35	28	35	20	267	867	-
3	12	27	91	31	32	31	33	25	271	921	-
4	14	18	81	23	27	24	29	19	264	964	-
5	13	26	93	28	20	28	23	22	268	868	-
6	14	16	130	20	38	21	39	18	327	933	Tachycardia
7	11	26	101	29	35	29	34	21	268	968	Tachycardia
8	17	21	101	28	40	28	42	21	256	856	-
9	11	19	81	25	32	25	32	16	267	767	-
10	13	22	98	28	35	29	35	21	266	866	Paralytic ileus
11	13	19	128	22	28	22	28	16	277	820	Paralytic ileus
12	13	19	100	24	35	25	34	19	301	744	-
13	12	25	85	29	30	29	32	20	266	806	-
14	11	20	95	26	35	26	37	20	270	760	-
Mean	13	21.6	98	26.2	34 (65%)	26.7	35 (64%)	19.8	273	859	-

FVC before and after operation (26.2% vs 26.7%). Curve correction was excellent but the operation did not increase FVC. FVC continued to decrease after operation and it was 19.8% (range, 16–25%) at two years after operation. The scoliotic curvature at two years after operation was 35° (range, 23°–42°) (64%) and 35° (range, 23°–42°) (64%) at the last follow-up. Maintenance of correction was excellent. Figure 4 is a radiographic example.

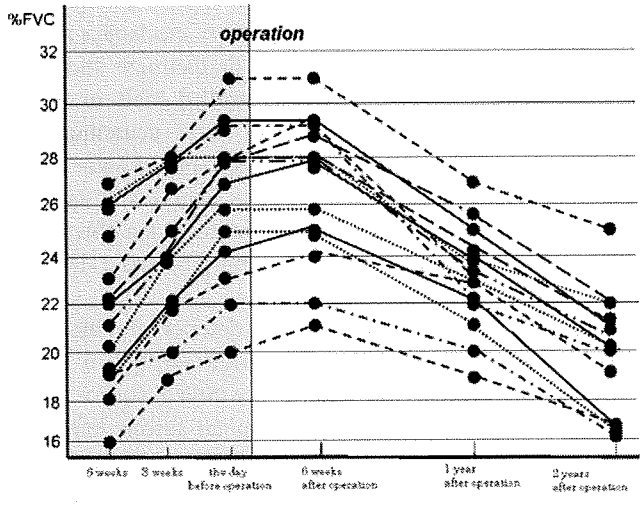

Fig. 3 Changes in FVC are demonstrated. After preoperative respiratory muscle training for six weeks, FVC increased in all patients. Although FVC of 13 patients did not exceed 30% at the time of operation, all 14 patients underwent surgical correction of scoliosis successfully without any complications. At six weeks after operation, FVC remained stable or increased slightly. FVC decreased in all patients at one year and two years after operation

Five minor complications occurred immediately after operation. Three of five were transient tachycardia for about seven days due possibly to the presence of profound cardiomyopathy but they were treated successfully with medications and resolved uneventfully. Two had paralytic ileus, both of which were treated only by observation without oral intake and cleared in 48 hours. No respiratory complications such as postoperative pneumonia or prolonged respiratory dependence were found. There were no neurological complications, infection or instrumentation failure during the study period. Up to the present, all patients are still alive at 3.5 years (range, 2.0–5.5 years) after operation.

Discussion

Posterior spinal fusion for scoliosis in DMD should be done early enough in the course of curve progression, when pulmonary and cardiac function are sufficient, so the patients can be anaesthetised and operated upon relatively safely and in order to reduce the likelihood of major complications [3, 5, 7–9, 11, 18–22]. Some authors recommended early operation on these patients in order to avoid anaesthetic, peri/postoperative complications [3, 5, 7–9, 18–22]. Correction or prevention of scoliosis by posterior spinal fusion has been highly effective in stabilising the spine and maintaining seating balance and comfort, and it is accepted as the optimal procedure [3, 8, 18–22]. However, this major procedure is accompanied by many significant complications [3, 9, 16–18]. These complications include superficial and deep wound infection, pseudoarthrosis of the fusion, which may result in pain, progression of the deformity, and implant failure. Furthermore, due to the cardio-

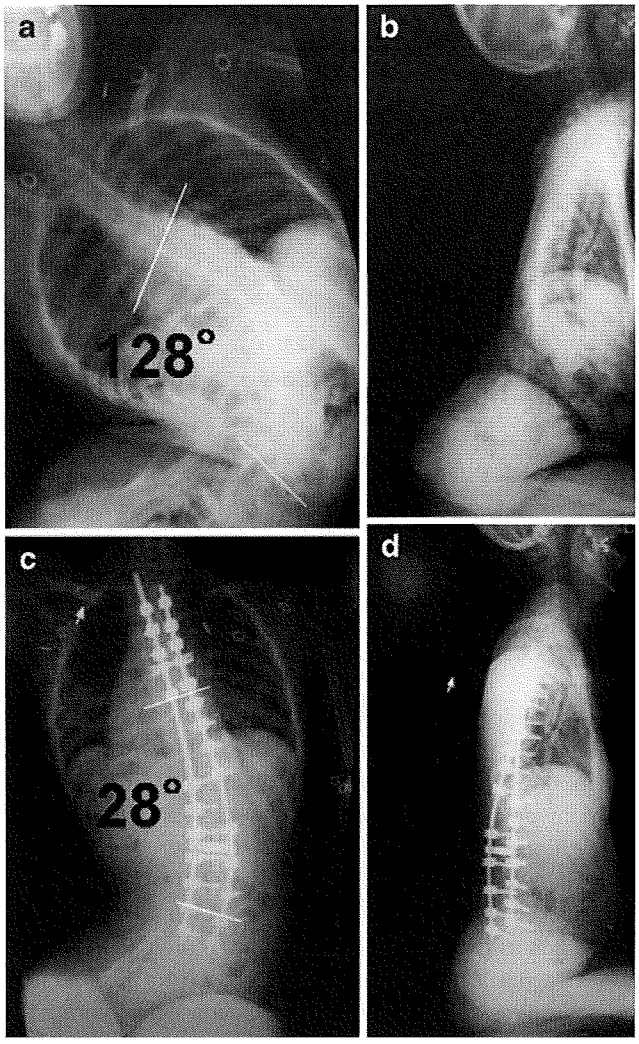

Fig. 4 Preoperative sitting radiographs of a 12-year-old boy with-Duchenne muscular dystrophy (DMD). Anteroposterior radiograph shows a severe scoliosis of 128°. FVC at sixweeks before operation was 19% and FVC increased to 22% the day before operation. **C** and **D** Surgical correction of scoliosis was performed successfully. Successful extubation was performed on the operative day. Postoperative sitting views show significant coronal correction of 28° (78%). At six weeks after operation, FVC remained stable at 22%

pulmonary compromise of these patients, they are more susceptible to postoperative pneumonia, prolonged respirator dependence, and death. Significant complication rates from 44% to 62% have been reported in some studies [3]. To the best of our knowledge, there has been little information about clinical outcomes and peri/postoperative complications in DMD patients with scoliosis and poor pulmonary function undergoing spine surgery.

Surgeons are often reluctant to perform elective surgery on patients who are respirator dependent or whose forced vital capacities or vital capacities do not exceed 40% of predicted normal [2]. Usually, the limits for the operation are not the extent of the curvature but a minimum forced vital capacity of about 30% of normal [9, 14, 18, 19]. Several previous studies have attempted to quantify peri/postoperative complications in patients with various diagnoses and poor pulmonary function undergoing surgery for scoliosis. In 1977, Sakai et al. [17] recommended preoperative tracheotomy if the FVC was less than 40% of predicted normal in patients with DMD undergoing scoliosis surgery. In 2005, Bach et al. [2] referred to the role of noninvasive ventilation and noted that all patients with neuromuscular scoliosis were extubated by the third postoperative day and maintained by noninvasive intermittent positive-pressure ventilation (IPPV). Despite continuous ventilator dependence, no patient developed any postoperative respiratory complications or required a tracheotomy. In our method, all patients had preoperative respiratory muscle training using pulmonary trainers for six weeks after admission and the FVC increased. Then, surgical correction of scoliosis was undertaken and extubation on the operative day was also undertaken. In our series, FVC in all patients increased. However, 13 of 14 patients had FVC of less than 30% at the time of operation. Then, surgical correction of scoliosis was performed successfully, and extubation was performed on the operative day for all patients without any respiratory complications. However, if respiratory complications occur, noninvasive intermittent positive-pressure ventilation (IPPV) or other kinds of assistance of breathing including reintubation and tracheotomy should be considered.

We used Threshold IMT for preoperative respiratory muscle training. Current consensus statements confine recommendation of IMT to patients with inspiratory muscle weakness [15]. As well as in patients with obstructive lung disease, there is a theoretical rationale for strengthening the inspiratory muscles of any patient who experiences inappropriate breathlessness, abnormal respiratory mechanics and/or inspiratory muscle weakness/fatigue. Furthermore, there are a small number of randomised, controlled trials in which IMT has elicited a positive effect upon neuromuscular diseases [23, 24] as well as less rigorously designed and executed studies in conditions such as kyphoscoliosis [10]. Although the number of our patients is small, the efficacy of preoperative respiratory training using Threshold IMT is shown clinically in this study.

Prevention of pulmonary function deterioration has been one of the important goals of scoliosis surgery in DMD patients. Because of the lack of controlled studies, it is uncertain as to whether posterior spinal fusion improves pulmonary function. There are few reports indicating that the rate of pulmonary function deterioration is reduced by surgical correction of scoliosis [6–8]. Kurz et al. [14] suggested negative mechanical effects of the deformed thorax associated with scoliosis on the underlying lung. However, many studies have reported that the surgical correction of scoliosis does not increase FVC and suggested that longevity is not increased by posterior spinal fusion

[4], and prevention or correction of scoliosis in DMD does not alter the decline in pulmonary function, nor does it improve survival [1, 12, 14, 20, 21].

Thus, although there have been controversies regarding the effect of posterior spinal fusion on pulmonary function, there is overwhelming support in the literature regarding the beneficial effects of well-timed posterior spinal fusion on the general well-being of DMD patients [5, 7]. Many studies noted that most patients and their families believed that posterior spinal fusion improved their function, cosmesis, seating balance and quality of life [1, 3, 5, 7–9, 16].

While our patients presented late at the time of operation, surgical correction was performed successfully with no respiratory complications. Also, despite preoperative severe scoliosis in all patients, curve correction and maintenance of correction was excellent. Although longer-term follow-up must be performed to determine the final fate of this series, this study shows that our patients with high-risk pulmonary dysfunction and severe scoliosis in DMD could undergo surgical correction of scoliosis with general anaesthesia after respiratory muscle training. Severe scoliosis with poor pulmonary function in DMD patients has been considered a reason to avoid surgery because of the fear of peri/postoperative respiratory complications. However, we felt such patients with FVC considered too low to permit reasonable surgical risk could undergo surgery and could benefit from posterior spinal fusion for scoliosis and pelvic obliquity.

Conclusions

FVC in DMD patients increased after respiratory muscle training using Threshold IMT. DMD patients with severe scoliosis and FVC considered too low to permit reasonable surgical risk could undergo surgery with general anaesthesia without respiratory complications and could benefit from posterior spinal fusion for scoliosis and pelvic obliquity.

Competing interests The authors declare that they have no competing interests. The funding source had no involvement in the decision to submit the paper for publication.

References

1. Askin GN, Hallettv R, Hare N, Webb JK (1997) The outcome of scoliosis surgery in the severely handicapped child: an objective and subjective assessment. Spine 22:44–50
2. Bach JR, Sabharwal S (2005) High pulmonary risk scoliosis surgery. J Spinal Disord Tech 18:527–530
3. Benson ER, Thomson JD, Smith BG, Banta JV (1998) Results and morbidity in a consecutive series of patients undergoing spinal fusion for neuromuscular scoliosis. Spine 23:2308–2317
4. Borg GA (1982) Psychophysical bases of perceived exertion. Med Sci Sports Exerc 14:377–381
5. Bridwell KH, Baldus KE, Iffrig TM (1999) Process measures and patient/parent evaluation of surgical management of spinal deformities in patients with progressive flaccid neuromuscular scoliosis. Spine 24:1300–1309
6. Brooke MH, Fenichel GM, Griggs RC, Mendell R, Moxley R, Florence J et al (1989) Duchenne muscular dystrophy: patterns of clinical progression and effects of supportive therapy. Neurology 39:475–481
7. Galasko CSB, Williamson JB, Delaney CM (1995) Lung function in Duchenne muscular dystrophy. Eur Spine J 4:263–267
8. Galasko CBS, Delany C, Morris P (1992) Spinal stabilisation in Duchenne muscular dystrophy. J Bone Joint Surg Br 74:210–220
9. Gill I, Eagle M, Mehta JS, Gibson MJ, Bushby K, Bullock R (2006) Correction of neuromuscular scoliosis in patients with preexisting respiratory failure. Spine 31:2478–2483
10. Hornstein S, Inman S, Ledsome JR (1987) Ventilatory muscle training in kyphoscoliosis. Spine 12:859–863
11. Hsu JD (1983) The natural history of spinal curve progression in the nonambulatory Duchenne muscular dystrophy patient. Spine 8:771–775
12. Kennedy JD, Staples AJ, Brook PD, Parsons DW, Sutherland AD, Martin AJ et al (1995) Effect of spinal surgery on lung function in Duchenne muscular dystrophy. Thorax 50:1173–1178
13. Klefbeck B, Nedjad JH (2003) Effect of inspiratory muscle training in patients with multiple sclerosis. Arch Phys Med Rehabil 84:994–999
14. Kurz LT, Mubarak SJ, Schultz P, Park SM, Leach J (1983) Correlation of scoliosis and pulmonary function in Duchenne muscular dystrophy. J Paediatr Orthop 3:347–355
15. McConnell AK, Romer LM, Weiner P (2005) Inspiratory muscle training in obstructive lung disease: how to implement and what to expect. Breathe 2:39–49
16. Oda T, Shimizu N, Yonenobu K, Ono K, Nabeshima T, Kyoh S (1993) Longitudinal study of spinal deformity in Duchenne muscular dystrophy. J Paediatr Orthop 13:478–488
17. Sakai DN, Hsu JD, Bonnett DA, Brown JC (1977) Stabilization of the collapsing spine in Duchenne muscular dystrophy. Clin Orthop 128:256–260
18. Shapiro F, Specht L (1993) The diagnosis and orthopaedic treatment of inherited muscular diseases of childhood. J Bone Joint Surg Am 75:439–445
19. Smith A, Koreska J, Mosley CF (1989) Progression of scoliosis in Duchenne muscular dystrophy. J Bone Joint Surg Am 71:1066–1074
20. Sticker U, Moser H, Aebi M (1996) Predominantly posterior instrumentation and fusion in neuromuscular and neurogenic scoliosis in children and adolescents. Euro Spine J 5:101–106
21. Sullivan JA, Conner SB (1982) Comparison of Harrington instrumentation and segmental spinal instrumentation in the management of neuromuscular spinal deformity. Spine 7:299–304
22. Sussman MD (1984) Advantage of early spinal stabilization and fusion in patients with Duchenne muscular dystrophy. J Paediatr Orthop 4:532–538
23. Topin N, Matecki S, Le Bris S (2002) Dose-dependent effect of individualized respiratory muscle training in children with Duchenne muscular dystrophy. Neuromuscul Disord 12:576–583
24. Wanke T, Toifl K, Merkle M, Formanek D, Lahrmann H, Zwick H (1994) Inspiratory muscle training in patients with Duchenne muscular dystrophy. Chest 105:475–482
25. Yamashita T, Kanaya K, Yokogushi K, Ishikawa Y, Minami R (2001) Correlation between progression of spinal deformity and pulmonary function in Duchenne muscular dystrophy. J Pediatr Orthop 21:113–116

International Orthopaedics (SICOT)
DOI 10.1007/s00264-010-0986-8

ORIGINAL PAPER

Less invasive and less technically demanding decompressive procedure for lumbar spinal stenosis—appropriate for general orthopaedic surgeons?

Masashi Takaso · Toshiyuki Nakazawa · Takayuki Imura · Takamitsu Okada · Kensuke Fukushima · Masaki Ueno · Wataru Saito · Ryousuke Shintani · Hiroyuki Sakagami · Kazuhisa Takahashi · Masashi Yamazaki · Seiji Ohtori · Toshiaki Kotani

Received: 31 January 2010 / Revised: 3 February 2010 / Accepted: 8 February 2010

Abstract This article presents the clinical and radiological results of the modified spinous process osteotomy decompressive procedure (MSPO), which affords excellent visualisation and provides wide access for Kerrison rongeur use and angulation while minimising destruction of tissues not directly involved in the pathological process. A total of 50 patients with degenerative lumbar spinal stenosis underwent MSPO between 2002 and 2005. The minimum follow-up period was five years. Patient's walking distance ability was 85.4 m (5–180 m) preoperatively and 2,560 m (1500–8000 m) at the last follow-up. Leg pain improved in 100% of the patients and back pain improved in 89% at the last follow-up. The overall results were good to excellent in 90% of the patients, fair in 16% and all patients were satisfied with the outcome at the last follow-up. The osteotomised spinous process eventually united with the retained laminar bridge in all patients within nine months after surgery. Degenerative lumbar spinal stenosis can be adequately decompressed with less violation of the integrity of the posterior elements using MSPO. The described technique of MSPO yielded promising results with few complications. The authors believe MSPO is less technically demanding and appropriate for general orthopaedic surgeons, occasional spine surgeons and chief residents.

M. Takaso (✉) · T. Nakazawa · T. Imura · T. Okada · K. Fukushima · M. Ueno · W. Saito · R. Shintani
Department of Orthopaedic Surgery, Kitasato University, School of Medicine,
Kitasato1-15-1, Sagamihara,
Kanagawa, Japan
e-mail: mtakaso@kitasato-u.ac.jp

H. Sakagami
Department of Anatomy and Cell Biology, Kitasato University, School of Medicine,
Kitasato1-15-1, Sagamihara,
Kanagawa, Japan

K. Takahashi · M. Yamazaki · S. Ohtori · T. Kotani
Department of Orthopaedic Surgery, Chiba University, School of Medicine,
Inohana 1-8-1, Chiba,
Chiba, Japan

Published online: 14 March 2010

Introduction

Degenerative lumbar spinal stenosis is the most common condition leading to spine surgery in the geriatric population [6, 12–14]. With the increasing longevity of our population and a continually rising proportion of elderly patients, back and leg pain may cause loss of functional capabilities including activities of daily living and is a significant health care issue [3, 4, 13]. Therefore, surgery for symptomatic lumbar spinal stenosis is becoming increasingly more common for orthopaedic surgeons.

Extensive lumbar laminectomy has been used for the treatment of degenerative lumbar spinal stenosis, while affording wide surgical exposure and complete decompression [6, 9, 10]. However, this technique causes destruction of surrounding tissues, postoperative low back pain secondary to paraspinal muscle atrophy and iatrogenic biomechanical instability [3, 7, 9, 10, 12, 19, 21, 22].

Currently, there has been increased awareness of the need to preserve stability and minimise destruction to tissues not directly involved in the pathological process. Several authors have described their experiences with minimally invasive surgery (i.e. microscopic/microendoscopic decompression) for this pathology and reported its efficacy and safety. However, these techniques are techni-

cally demanding even though their results have been reported to be favourable [1, 5, 11, 15, 22].

Less invasive and less technically demanding alternatives are needed. The surgical technique of spinous process osteotomy decompressive procedure (SPO), which affords excellent visualisation and a wide access available for Kerrison use and angulation while minimising destruction of tissues not directly involved in the pathological process, was initially described by Yong Hing and Kirkaldy-Willis [23] and some modifications have been added [21]. Although excellent clinical outcomes of SPO with a short-term follow-up were described in 1999 [21], further analysis has not been performed. Also, the fate of the osteotomised spinous processes has remained uncertain.

We have modified the original SPO and have performed modified SPO (MSPO) for patients with degenerative lumbar spinal stenosis. The purpose of this study was to assess clinical and radiological outcomes of MSPO for degenerative lumbar spinal stenosis and determine the fate of the osteotomised spinous processes.

Surgical technique

In order to decompress one segment, a posterior-midline skin incision of approximately 30 mm was made. The dorso-lumbar fascia was incised to preserve the supra-spinous ligamentous attachment to the fascia. Only one cephalad spinous process at the involved segment should be included (Fig. 1a,b). To obtain excellent visualisation, one level of spinous process should be fully exposed. When L4/L5 spinal canal stenosis is decompressed, the L4 spinous process should be located and exposed. The spinous process of the involved segments is located and paraspinal musculature is stripped unilaterally from its spinous and laminar attachments, with care being taken not to extend subperiosteal dissection beyond the medial portion of the facet joint. Then, at the base of the spinous process, superficially to the junction of the lamina, the spinous process is osteotomised using a curved osteotome (Fig. 1c). A Cobb elevator was used to retract through the inter spinous notch on the contralateral side and against the multifidus ipsilaterally, which provides wide exposure of the segments to be decompressed with the use of the Gelpy self-retaining retractor. Then, a full view of the interlaminar space is afforded (Fig. 1d). Stripping and retraction of paraspinal musculature should not extend to the facet joint on the contralateral side. Decompression through a limited laminotomy of the cephalad lamina was performed under excellent visualisation and was extended in a trumpeted undercutting technique to enhance decompression of the spinal canal, lateral recess and foraminal stenosis. Limited laminotomy is also performed on the caudal lamina. The authors also suggest the use of laminar spreaders to avoid major bone resection as the majority of neurological compression occurs not under the lamina but at the level of the interlaminar window and under the facet joints. The ligamentum flavum is resected from cephalad to caudal, from medial to lateral. Finally, complete decompression for the dural sac and the nerve roots is confirmed (Fig. 1e, f). This limited laminotomy should be performed to preserve the facet joints and pars interarticularis completely.

The authors suggest the contralateral lamina should be retained as much as possible to contact with the osteotomised spinous process after the retractor is removed, while complete decompression is performed. The retractor was removed and the osteotomised spinous process resumes its native position in contact with the cotralateral retained lamina. The dorsolumbar fascia was resutured to the supraspinous ligament/dorsolumbar fascia complex with the ostetomised spinous process. An standard skin suture was performed with one drainage tube (Fig. 1g, h). Figure 2 shows the surgeon's angle of view.

Materials and methods

A total of 50 patients (30 males and 20 females) with degenerative lumbar spinal stenosis underwent MSPO between 2002 and 2005. Inclusion criteria required that each patient had: (1) neurological claudication as defined by leg pain limiting standing, ambulation, or both; (2) a history of exercise intolerance; (3) magnetic resonance imaging (MRI), myelogram confirmation of one-level compressive cetral stenosis with or without lateral recess stenosis; (4) no or mild back pain; and (5) failure of conservative therapy after an adequate trial. Patients with degenerative sondylolisthesis, developmental stenosis, radiographic signs of instability and incomplete decompression from previous surgery were not involved in this study. Thirty-two patients were operated on by the corresponding author (M.T.) and 18 patients were operated on by two general orthopaedic surgeons or two chief residents. All patients were available for a minimum of five-years follow-up.

A distinction was made between leg and back pain, each of which was scored subjectively for severity on the visual analogue scale (VAS). A thorough medical history was obtained to identify comorbid medical factors. Walking tolerance was described in terms of distance.

After surgery, an independent observer who was not involved in the patients' care contacted all patients on two separate occasions (at two years after surgery and at the last follow-up)

Outcome variables and nomenclature were adopted from a published meta-analysis to permit comparisons with the existing literature. The ultimate clinical outcome was assessed by the criteria by Stucki et al. [18] at two years after surgery

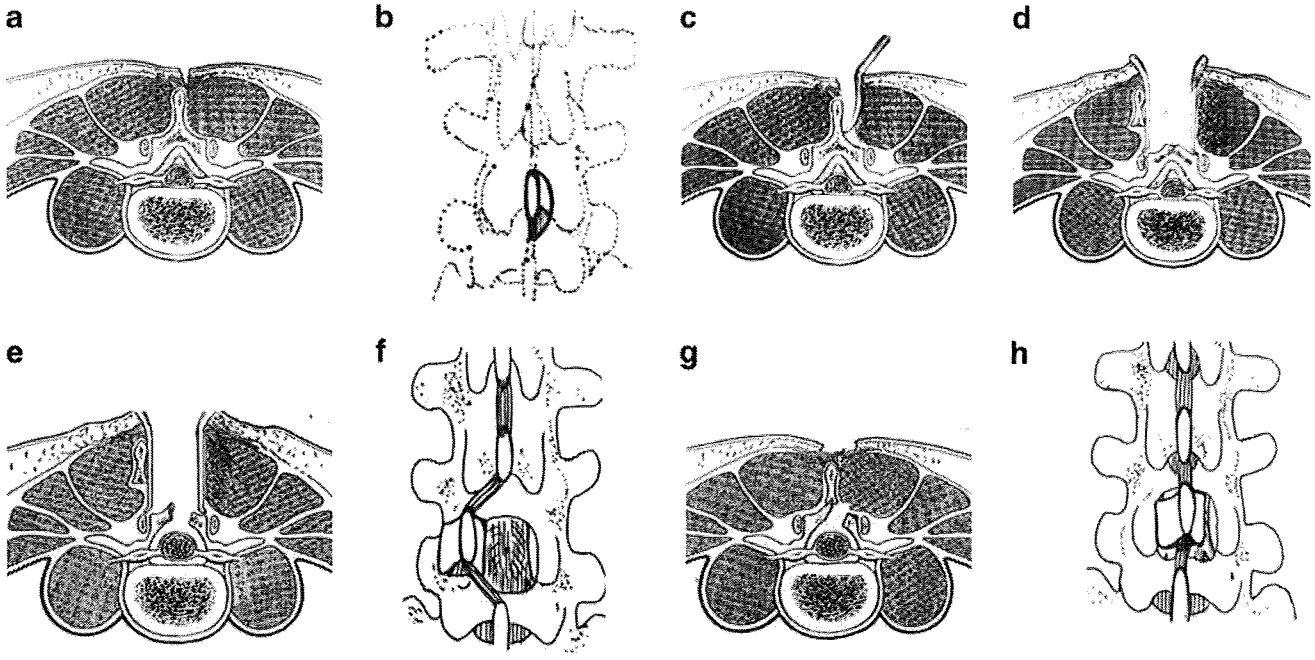

Fig. 1 Surgical technique. **a**, **b** Midline posterior incision. **c** Spinous process osteotomy using curved osteotome. **d** Retraction by Gelpy self-retaining retractor. **e**, **f** Spinal canal decompression by undermining of lamina. **g**, **h** Closure of dorso-lumbar fascia

and at the last follow-up. In that report, functional outcome was divided into one of three categories (Table 1).

A self-administered questionnaire was sent to the all patients to determine patient satisfaction with the outcome using a four-point patient satisfaction measure (dissatisfied, minimally satisfied, satisfied, very satisfied) at two years after surgery and at the last follow-up.

CT scans were performed to determine the fate of the osteotomised spinous process at three months, six months, nine months and 12 months after surgery and at the last follow-up.

Results

Fifty patients were enrolled into this study. Table 2 reflects the patient demographics and surgical parameters. The average age at surgery was 72 years (range, 50–86 years). The average follow-up period was 6.7 years (range, five to eight years). Forty-one patients had decompression at L4/5, six at L3/4, and three L2/3. The average operating time was 42 minutes (range, 29–66 minutes). The average estimated blood loss was 55 ml (range, 22–112 ml). No blood transfusion was required in any of the patients.

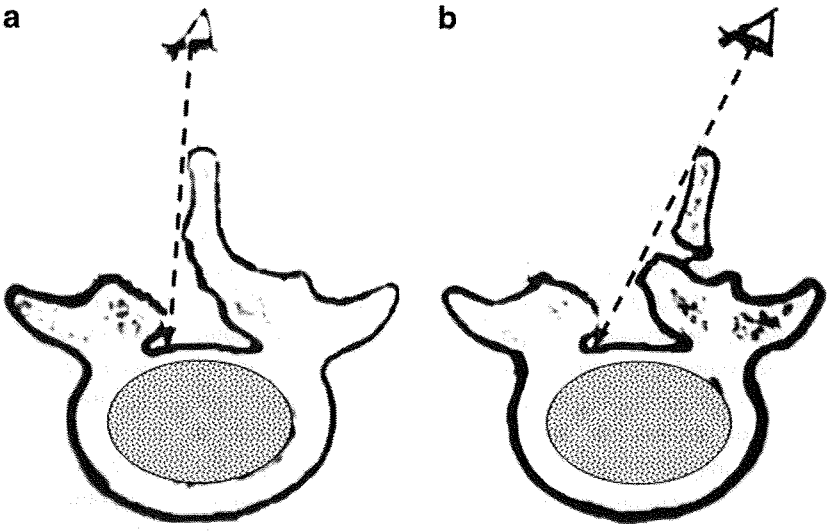

Fig. 2 The surgeon's angle of view. **a** In a case without spinous process osteotomy. The retained midline posterior structures significantly limit visualization and Kerrison angulation as the surgeon attempts to undercut the lateral zone in cases of nerve root canal stenosis. **b** In a case with spinous process osteotomy. The angle of view is increased to permit easy examination of the lateral recess and foramen

Table 1 Clinical and functional outcome

Rating	Description
Good to excellent	A patient with a good to excellent outcome had absent or occasional mild back and leg pain. Additionally, it was required that good to excellent patients be able to ambulate more than one mile or 20 minutes, and that they not restrict themselves from their usual activities.
Fair	A fair result implied persistent mild back or leg pain with occasional moderate pain, and less than one mile or 20 minutes of ambulation endurance. These patients also acknowledged some mild restrictions in their customary physical activity.
Poor	A poor result implied little to no pain relief from surgery, major activity limitations, or both. A repeat operation for any reason was considered a poor result, regardless of the ultimate level of function.

Intraoperative complications occurred in two patients, both of which were dural tears (one by the corresponding author and one by a chief resident). All tears were a result of Kerrison rongeur work and repaired immediately without clinical sequelae. No postoperative complication occurred in any of our series. There was no re-operation during the follow-up period.

The result of this study is summarised in Table 3. According to the meta-analysis criteria, the overall results were good to excellent in 84% (42/50) of the patients and fair in 16% (8/50) at two years after surgery. At the last follow-up, the overall results were good to excellent in 90% (45/50) of the patients and fair in 16% (5/50).

Table 2 Patient demographics and surgical details

Demographic	Description
Gender	30 males; 20 females
Age (years)	Average 72 years (range, 50–86 years)
Comorbidities	
HT	20% (10/50)
CAD	6% (3/50)
MI	4% (2/50)
NIDDM	20% (10/50)
CVA	4% (2/50)
COPD	6% (3/50)
Osteoporosis	14% (7/50)
Rheumatoid arthritis	4% (2/50)
Operating time	42 minutes (range, 29–66 minutes)
Blood loss	55 ml (range, 22–112 ml)

HT hypertension, *CAD* history of coronary artery disease, *MI* history of myocardial infarction, *NIDDM* non-insulin-dependent diabetes mellitus, *CVA* cerebrovascular accident, *COPD* chronic obstructive pulmonary disease

Table 3 Two-year and last surgical follow-up

Rating	Two-year follow-up	Last follow-up
Good to excellent	84% (42)	90%
Fair	16% (8)	10%
Poor	0% (0)	0%
Improvement		
Leg pain	100% (50/50)	100% (50/50)
Back pain	80% (36/45)	89% (40/45)
Satisfaction	100% (50/50)	100% (50/50)

Before surgery, walking distance ability was 85.4 m (range, 5–180 m). It was 2,066 m (1200–8000 m) at two years after surgery and 2,560 m (1500–8000 m) at the last follow-up.

The average preoperative leg pain level was 6.7 (range, 4–10). The average leg pain level was 1.0 (range, 0–2) at two years after surgery and the last follow-up was 0.7 (range, 0–2). At two years after surgery, 80% (40/50) of the patients reported that leg pain had resolved; 20% (10/50) judged the pain to be better. At the last follow-up, 90% (45/50) of the patients reported that leg pain had resolved; 10% (5/50) believed the pain to be better.

In 10% (5/50) of the patients, back pain was not a preoperative problem. The average preoperative low back pain level was 1.5 (range, 0–3). The average low back pain level was 0.7 (range, 0–2) at two years after surgery and at the last follow-up it was 0.5 (range, 0–2). At two years after surgery, 40% (18/45) of the patients reported back pain was absent; 40% (18/45) believed the pain was improved; 20% (9/45) stated no change in the level of pain. At the last follow-up, 60% (27/45) of the patients reported back pain was absent; 40% (18/45) believed the pain was improved. Ninety percent (45/50) of the patients were very satisfied with their outcome, 8% (4/50) were satisfied, and 2% (1/50) were minimally satisfied. No patients were dissatisfied.

CT scans were performed to assess fusion status between the osteotomised spinous process and the retained laminar bridge. CT scans demonstrated the osteotomised spinous process united with the contralateral retained laminar bridge in 10% (5/50) of the patients at three months after surgery, in 80% (40/50) at six months after surgery and in 100% (50/50) at nine months after surgery. The union was maintained in all patients at the last follow-up.

Figure 3 shows a patient example.

Discussion

Commonly used techniques of lumbar decompression that include bilateral elevation of paraspinal musculature and aggressive bony resection can result in significant iatrogen-

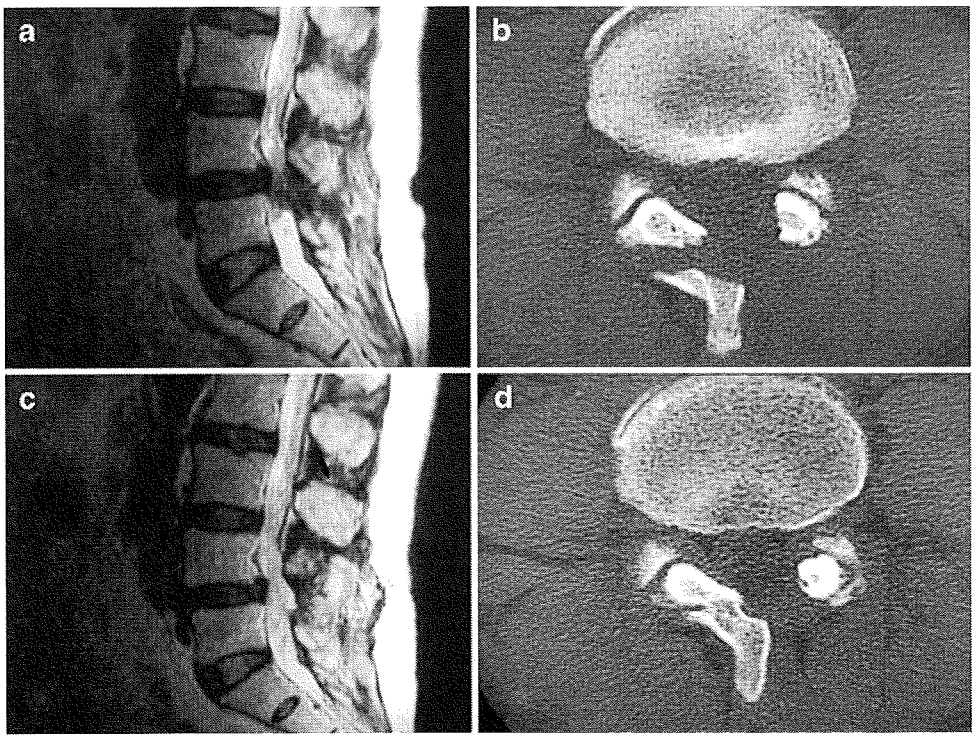

Fig. 3 A 60-year-old male with degenerative lumbar spinal stenosis at the L4/5 level. Before surgery, walking ability distance was 90 m. Preoperative low back pain level was 3 (10-point visual analogue scale). Preoperative leg pain level was 7. **a** A preoperative MRI. **b** The osteotomised spinous process. **c** An MRI at three months after surgery. **d** The osteotomised spinous process united with the retained laminar bridge at six months after surgery. At 2.5 years after surgery, walking distance was 7000 m. Leg pain level was 1 and low back pain level was 1. This patient was very satisfied with the outcome

ic sequelae. The paraspinal muscles may be denervated and subsequent atrophy may occur. Theses changes have been associated with the postoperative failed back syndrome. Also, classical surgical decompression has involved extensive removal of the posterior elements including the lamina, spinous processes, supra-/interspinous ligaments, and occasionally the facet joints [6, 7, 10]. Surgical removal of these posterior elements compromises spinal stability. Older techniques of laminectomy or unroofing of the spinal canal, while affording wide decompression, often resulted in destruction or insufficiency of the pars interarticularis or facet joints with resultant iatrogenic instability [3, 9, 12, 21]. Extensive decompression is a must while preserving spinal stability. Concomitant spinal arthrodesis should be considered when spinal stability is lost [3, 4, 8, 9]. However, spinal fusion in elderly patients is associated with higher complication and pseudarthrosis rates [2–4, 16, 17].

Fenestration techniques allow preservation of the spinous processes and supra-/interspinous ligaments, while decompression is afforded by bilateral elevation of the paraspinal musculature followed by bilateral laminotomies [21, 24]. However, the paraspinal muscles are still stripped and the retained midline posterior structures significantly limit visualisation and Kerrison angulation as the surgeon attempts to undercut the lateral zone in cases of nerve root canal stenosis [21].

Surgical treatment of degenerative lumbar spinal stenosis has become progressively less invasive. Several techniques of minimally invasive decompressive surgery for the treatment of lumbar spinal stenosis have been reported and their results have also been favourable [1, 5, 11, 15, 19, 22]. Microscopic/microendoscopic techniques involve unilateral paraspinal retraction, ipsilateral decompression, and contralateral decompression, using microscope/microendoscope and under the midline posterior structures. However, the ipsilateral portion of this technique is limited by visualisation and Kerrison angulation of the lateral zone. Also, working through the small operative window at a significant angle to address the contralateral side requires an extensive knowledge of lumbar microanatomy and considerable experience with both Kerrison and microscope/microendoscope to either obtain a complete decompression or avoid damage to neurological structures [5, 19, 22]. This technique has been described to be technically demanding and not a case for occasional spine surgeons or chief residents [22].

The recent rise in minimally or less invasive surgical techniques has been based on the honourable goals of minimisation of destruction to unaffected tissues and optimisation of the cosmetic results. These goals should be to achieve decompressive surgery completely and safely. MSPO appears to achieve these goals, while affording excellent visualisation and complete decompression. MSPO saves the posterior midline elements while allowing them to be retracted away from the working area, and it scrupulously respects the integrity of the spinous processes and supra-/interspinous ligaments while removing the ligamentum fravum and decompressing the lateral recess. In addition, the authors confirmed each osteotomised spinous

process united with the retained laminar bridge within nine months after surgery in all patients. Therefore, preservation of bony stability could be achieved.

Commonly used techniques of exposure for lumbar decompression that include elevation of the multifindus bilaterally with subsequent wide retraction have potentially serious consequences [7, 21]. Innervation of the multifidus derives from the medial branch of the dorsal ramus. Retraction of multifidus beyond the midpoint of the facet joint tethers the medial branch of the dorsal ramus, risking muscular denervation [21]. MSPO limits bilateral retraction to the level of the medial facet border. The authors believe MSPO minimises the risk of iatrogenic muscular trauma, and potential postoperative low back pain secondary to paraspinal muscle atrophy is avoided.

The process of MSPO can be accomplished with less surgical exposure and complexity, translating into decreased blood loss and operating time, with no major complication even though 18 operations were performed by several general orthopaedic surgeons and chief residents. Furthermore, the use of MSPO does not require any specific instruments or extensive experience. The authors believe MSPO is appropriate for chief residents or general orthopaedic surgeons.

Overall patient satisfaction was 100%. Leg pain was relieved in 100%. Back pain was improved in 89% of the patients even though this was not a primary goal of the surgery. Despite stricter outcome criteria than that used in the meta-analysis, good and excellent results after MSPO were 26% higher than that described by Turner et al. (90% vs. 64%) [20].

As with previous studies, the patients in this study had many comorbid medical conditions (Table 1). These conditions had an impact on their quality of life and functional capacity. Any surgery should offer significant functional benefits as the older and less healthy patient population is at high risk for complications. The authors also recommend MSPO for surgical treatment of degenerative lumbar spinal stenosis in elderly patients.

Conclusion

MSPO is less invasive and less technically demanding than other techniques. Degenerative lumbar spinal stenosis can be adequately decompressed with less violation of the integrity of the posterior elements using MSPO. MSPO provides for excellent visualisation and room to work while minimising resection and injury to tissues not directly involved in the pathological process. The osteotomised spinous process eventually united with the retained laminar bridge in all patients. The described technique of MSPO yielded promising results with few complications. Patient-focussed outcomes improved significantly after surgery. Patient's satisfaction was high.

Study limitations

There are some limitations to this study. There was no randomised control group. However, the purpose of this study was to compare the current technique of MSPO with established decompression and/or arthrodesis procedures described in the existing literature. In this study, only patients who had one-level decompression were included. It remains to be seen whether the described technique is adequate for multilevel decompression.

Conflict of interest statement No funds were received in support of this study.

The author(s) of this manuscript has/have chosen not to furnish International Orthopaedics and its readers with information regarding any relationship that might exist between a commercial party and material contained in this manuscript that might represent a potential conflict of interest.

No benefits in any form have been or will be received from a commercial party related directly or indirectly to the subject of this manuscript.

Informed consent was obtained from the all patients before entering the study.

Institutional review board approval of Kitasato University was obtained for this study.

References

1. Arai Y, Shinomiya K, Okawa A, Takahashi M, Kawabata S, Haro H et al (2007) Comparison between endoscopic and microscopic lumbar decompression using tubular retractor to perform minimally invasive surgery. J Jpn Soc Spine Surg Rel Res 18:654–657
2. Benz RJ, Ibrahim ZG, Afshar P, Garfin SR (2001) Predicting complications in elderly patients undergoing lumbar decompression. Clin Orthop Relat Res 384:116–121
3. Deyo RA, Cherkin DC, Loeser JD, Bigos SJ, Ciol MA (1992) Morbidity and mortality in association with operations on the lumbar spine. J Bone Joint Surg [Am] 74:536–543
4. Deyo RA, Ciol MA, Cherkin DC, Loeser JD, Bigos SJ (1993) Lumbar spinal fusion: a cohort study of complications, reoperations, and resource use in the medicare population. Spine 18:1463–1470
5. Foley KT, Smith MM (1997) Microendoscopic discectomy technique. J Neurosurg 3:301–307
6. Garfin SR, Herkowitz HN, Mirkovic S (1999) Spinal stenosis. J Bone Joint Surg [Am] 81:572–586
7. Gejo R, Kawaguchi Y, Kondoh T, Tabuchi E, Matsui H, Torii K, Ono T, Kimura T (2000) Magnetic resonance imaging and histologic evidence of postoperative back muscle injury in rats. Spine 25:941–946
8. Gelalis ID, Stafilas KS, Korompilias AV, Zacharis KC, Beris AE, Xenakis TA (2006) Decompressive surgery for degenerative lumbar spinal stenosis: long-term results. Int Orthop 30:59–63

9. Hanley EN Jr (1995) The indications for lumbar spinal fusion with and without instrumentation. Spine 20(suppl):S143–S153
10. Herron LD, Trippi AC, 8 Herron LD, Trippi AC (1989) L4–L5 degenerative spondylolisthesis (decompression laminectomy without fusion). Spine 14:534–538
11. Ikuta K, Arima J, Tanaka T (2005) Short-term result of microendoscopic posterior decompression for lumbar spinal stenosis. J Neurosurg 40:624–633
12. Katz JN, Lipson SJ, Larson MG (1991) The outcome decompressive laminectomy for degenerative lumbar stenosis. J Bone Joint Surg [Am] 73:809–816
13. Katz JN (1995) Lumbar spinal fusions: surgical rates, costs, complications. Spine 20(Suppl):S78–S83
14. Katz JN, Lipson SJ, Lew RA (1997) Lumbar laminectomy alone or with instrumented or noninstrumented arthrodesis in degenerative lumbar spinal stenosis: patient selection, costs, and surgical outcomes. Spine 22:1123–1131
15. Mikami Y, Ngasase M, Hase H, Hatta Y, Yanagisawa K, Harada T (2007) Microendoscopic decompression via interspinous midline approach. J Jpn Soc Spine Surg Rel Res 18:658–661
16. Ragab AA, Fye MA, Bohlman HH (2003) Surgery of the lumbar spine for spinal stenosis in 118 patients 70 years of age or older. Spine 28:348–353
17. Sanderson PL, Wood P (1993) Surgery for lumbar spinal stenosis in old people. J Bone Joint Surg [Br] 75:393–397
18. Stucki G, Daltory LH, Liang MH, Lipson SJ, Fossel AH, Katz JN (1996) Measurement properties of a self-administered outcome measure in lumbar spinal stenosis. Spine 21:796–803
19. Tsai RYC, Yang RS, Bray RS (1998) Microscopic laminotomies for degenerative lumbar spinal stenosis. J Spinal Disorder 11:389–394
20. Turner JA, Ersck M, Herron L, Deyo R (1992) Surgery for lumbar stenosis: attempted meta-analysis of the literature. Spine 17:1–8
21. Weiner BK, Fraser RD, Peterson M (1992) Spinous process osteotomy to facilitate lumbar decompressive surgery. Spine 24:62–66
22. Weiner BK, Walker M, Brower RS, McCulloch JA (1999) Microdecompression for lumbar spinal canal stenosis. Spine 24:2268–2272
23. Yong-Hing K, Kirkaldy-Willis H (1978) Osteotomy of the lumbar spinous process to increase surgical exposure. Clin Orthop 134:218–220
24. Young S, Veerapen O'Laire SA (1988) Relief of lumbar canal stenosis using multilevel subarticular fenestrations as an alternative to wide laminectomy: preliminary report. Neurosurgery 23:628–633

J Orthop Sci (2010) 15:171–177
DOI 10.1007/s00776-009-1437-5

JOURNAL OF
ORTHOPAEDIC SCIENCE

Original article

Two-year results for scoliosis secondary to Duchenne muscular dystrophy fused to lumbar 5 with segmental pedicle screw instrumentation

Masashi Takaso[1], Toshiyuki Nakazawa[1], Takayuki Imura[1], Takamitsu Okada[1], Masahiro Toyama[1], Masaki Ueno[1], Kensuke Fukushima[1], Wataru Saito[1], Atsushi Minatani[1], Gennyo Miyajima[1], Michinari Fukuda[1], Naonobu Takahira[1], Kazuhisa Takahashi[2], Masashi Yamazaki[2], Seiji Ohtori[2], Hirotsugu Okamoto[3], Toshiyuki Okutomi[3], Makito Okamoto[4], and Takashi Masaki[4]

[1]Department of Orthopaedic Surgery, Kitasato University, School of Medicine, Kitasato 1-15-1, Sagamihara, Kanagawa 228-8555, Japan
[2]Department of Orthopaedic Surgery, Chiba University, Graduate School of Medicine, Chiba, Japan
[3]Department of Anesthesiology, Kitasato University, School of Medicine, Sagamihara, Kanagawa, Japan
[4]Department of Otorhinolaryngology, Kitasato University, School of Medicine, Sagamihara, Kanagawa, Japan

Abstract

Background. Instrumentation and fusion to the sacrum/pelvis has been a mainstay in the surgical treatment of scoliosis in patients with Duchenne muscular dystrophy since the development of the intrailiac post. It is recommended for correcting pelvic obliquity. However, caudal extent of instrumentation and fusion has remained a matter of considerable debate. This study was performed to determine the efficacy and safety of stopping segmental pedicle screw constructs at L5 during surgical treatment of scoliosis associated with Duchenne muscular dystrophy (DMD).

Methods. From May 2005 to June 2007, a total of 20 consecutive patients underwent posterior spinal fusion and segmental pedicle screw instrumentation only to L5 for scoliosis secondary to DMD. All patients had progressive scoliosis, difficulty sitting, and back pain before surgery. A minimum 2-year follow-up was required for inclusion in this study. Assessment was performed clinically and with radiological measurements. The Cobb angles of the curves and spinal pelvic obliquity were measured on the coronal plane. Thoracic kyphosis and lumbar lordosis were measured on the sagittal plane. These radiographic assessments were performed before surgery, immediately after surgery, and at a 3-month interval thereafter. The operating time, blood loss, and complications were evaluated. Patients were questioned about whether they had difficulty sitting and felt back pain before surgery and at 6 weeks, 1 year, and 2 years after surgery.

Results. A total of 20 patients, aged 11–17 years, were enrolled. The average follow-up period was 37 months. Preoperative coronal curves averaged 70° (range 51°–85°), with a postoperative mean of 15° (range 8°–25°) and a mean of 17° (range 9°–27°) at the last follow-up. Pelvic obliquity improved from 13° (range 7°–15°) preoperatively to 5° degrees (range 3°–8°) postoperatively and 6° (range 3°–9°) at the last follow-up. Good sagittal plane alignment was recreated and maintained. Only a small loss of correction of scoliosis and pelvic obliquity was noted. The mean operating time was 271 min (range 232–308 min). The mean intraoperative blood loss was 890 ml (range 660–1260 ml). The mean total blood loss was 2100 ml (range 1250–2880 ml). There was no major complication. All patients reported that difficulty sitting and back pain were alleviated after surgery.

Conclusion. Segmental pedicle screw instrumentation and fusion only to L5 is safe and effective in patients with DMD scoliosis of <85° and pelvic obliquity of <15°. Good sagittal plane alignment was achieved and maintained. All patients benefited from surgery in terms of improved quality of life. There was no major complication.

Introduction

Duchenne muscular dystrophy (DMD) is the most common and severe form of muscular dystrophies.[1] The natural history of scoliosis in DMD patients has been well established. Natural history studies have demonstrated almost invariable progression of the scoliosis.[2,3] Severe scoliosis causes difficulty sitting, breakdown of the skin, and back pain.[2,3] Thus, progressive scoliosis requires surgical correction and stabilization. Posterior spinal fusion for scoliosis in DMD has been highly effective in stabilizing the spine and maintaining upright and comfortable sitting balance.[4–6]

Most reports on scoliosis surgery in patients with DMD have dealt with spinal instrumentation using hooks, wires, and hybrid constructs with lumbar pedicle screws.[1,7–11] However, it is difficult to provide strong and stable fixation with hook and wire anchors.[10,12] The intrailiac post, developed by Allen and Ferguson,[13] has provided a reliable means to achieve pelvic fixation and

Offprint requests to: M. Takaso
Received: September 13, 2009 / Accepted: November 3, 2009

address pelvic obliquity; however, the indications for extending the instrumentation and fusion to the pelvis or sacrum have remained controversial.[10,11] In addition, fusion only to L5 has been recommended in early cases without significant pelvic obliquity, whereas fusion to the sacrum/pelvis has been reserved for late cases with larger curves (>40°) and more severe pelvic obliquity (>10°).[11,14,15] The purpose of this study was to determine the efficacy and safety of stopping segmental pedicle screw instrumentation constructs at L5 in the treatment of spinal deformity associated with DMD.

Materials and methods

Informed consent was obtained from the all patients before entering the study. Institutional review board approval from Kitasato University was obtained for this study. The authors obtained an agreement for publication from institutional review board of Kitasato University.

From May 2005 to June 2007, a total of 20 consecutive patients underwent segmental pedicle screw instrumentation and fusion for scoliosis secondary to DMD. All patients had progressive scoliosis, difficulty sitting, and back pain before surgery. All of the operations were performed by the same surgeon. A minimum 2-year follow-up was required for inclusion in this study.

Surgical procedure and anesthetic technique

The primary aim of the surgery was to obtain a solid fusion, level pelvis, and balanced spine in the coronal and sagittal planes in these patients. All operations were performed under general anesthesia, mainly with propofol and remifentanil. These agents have only recently been marketed in Japan, with their rapid onset and emergence being their best advantages as anesthetics. Intraoperatively, spinal cord function was monitored by somatosensory/motor-evoked potentials.

The incision was midline and extends over. The posterior elements of the spine were exposed from the upper thoracic spine to the sacrum by stripping the muscles subperiosteally. The spinous process, the lamina, and the base of the transverse process of the vertebrae were stripped of periosteum. After removal of all soft tissue, local autograft bone was obtained from the spinous processes, laminae, and transverse processes of all the vertebrae, which did not support instrumentation, as a bone graft source. Spinal cord function was monitored throughout the procedure. Autotransfusion via preoperative storage and intraoperative collection was used. Correction of the curves was maintained by segmental pedicle screw and rod instrumentation. The spine was instrumented with the Expedium (DePuy Spine, Raynham, MA, USA). All curves were instrumented and fused from T3 or T4 to L5. For the segmental pedicle screw instrumentation, every level was instrumented on at least one side. No image-guided spinal navigation system was employed. Screws were placed with free-hand technique. Fluoroscopy was employed to confirm acceptable screw position. The segmental pedicle screw correction was performed with rod insertion, rod rotation, translation of the rod, appropriate distraction, and compression to level the proximal and distal end vertebra. Extensive posterior elements' decortication for local bone graft was performed using a motorized gouge. The local bone graft was packed onto the prepared surfaces and placed in each facet. The wound was sutured in three layers with two drainage tubes.

Assessment of results

Assessment was performed clinically and with radiological measurements. Patients were reviewed clinically and questioned about whether they had difficulty sitting or felt back pain before surgery and at 6 weeks, 1 year, and 2 years after surgery. Back pain was measured by a visual analogue scale (VAS). All patients were assigned pain-scale scores before surgery and at 6 weeks, 1 year, and 2 years after surgery. Sitting postero-anterior and lateral radiographs were obtained the day before surgery, immediately after surgery, and at 3 month after surgery. The Cobb angles of the curves were measured on the coronal plane; and thoracic kyphosis between T3 and T12 and lumbar lordosis between L1 and L5 were measured on the sagittal plane. Spinal pelvic obliquity (the angle between the perpendicular of the spine line from T1 to S1 and a line across the top of the pelvis) was measured (Fig. 1). Fusion was defined as (1) stable coronal and sagittal alignment during the follow-up period; (2) no clinical complaints; (3) no evidence of nonunion; and (4) stable hardware. All four criteria must be present to meet the definition of fusion.

Results

Twenty patients (all boys) were prospectively enrolled into this study. No patients were lost to follow-up. Demographic details and surgical parameters for the study group patients are shown in Table 1, and the radiographic measurements are shown in Table 2. The mean age at surgery was 13 years 2 months (range 11 years 8 months to 17 years 2 months). All scoliosis curves were single curves (14 right thoracolumbar, 3 left thoracolumbar, 3 right thoracic). The mean number of levels fused was 14.2 (range:14–15). The mean operating time was 271 min (range 232–308 min). The mean

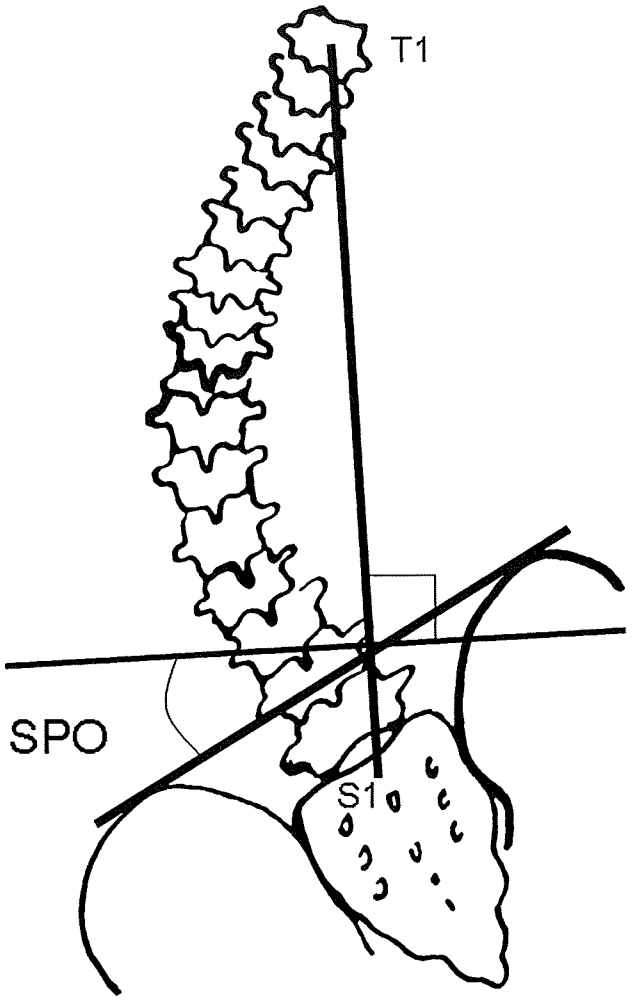

Fig. 1. Technique of determining the spinal-pelvic obliquity (*SPO*) where the angle between the perpendicular of the spine line from T1 to S1 and the line across the top of the pelvis is measured

intraoperative blood loss was 890 ml (range 660–1260 ml). The mean total blood loss was 2100 ml (range 1250–2880 ml). The mean follow-up period was 37 months (range 26–53 months).

On the coronal plane, the average preoperative coronal curve measured 70° (range 51°–85°), and the mean immediate postoperative coronal curve measured 15° (range 8°–25°). At the last follow-up, the mean curve measured 17° (range 9°–27°), and we noticed no more than 4° in the loss of correction in all patients at the last follow-up. On the sagittal plane, the mean preoperative sagittal thoracic curve (T3-T12) measured 7° (range –8° to 23°). The mean postoperative sagittal thoracic curve measured 19° (range 12°–28°). At the last follow-up, this curve measured 20° (range 13°–27°). The mean preoperative sagittal lumbar curve (L1-L5) measured 20° (range –18° to 58°), including kyphotic patients; and the mean immediate postoperative curve measured 35° (range 8°–46°). This curve measured 36° (range 7°–44°) at the last follow-up. No significant loss of correction in the coronal and sagittal plane was noted. The pelvic obliquity improved from a preoperative mean of 13° (range 7°–15°) to a postoperative mean of 5° (range 3°–8°) and 6° (range 3°–9°) at the last follow-up. Balanced sitting posture was achieved in all

Table 1. Details of the patients and operative parameters in the study group

Patient	Age (years)	Follow-up (months)	Operating time (min)	Intraoperative blood loss (ml)	Total blood loss (ml)
1	11	53	248	880	2110
2	13	53	260	870	1880
3	13	52	270	900	1920
4	13	48	266	780	2230
5	13	46	277	900	1670
6	12	42	308	890	1890
7	12	42	345	890	2000
8	14	40	367	970	2100
9	13	38	398	898	2200
10	11	37	399	1260	2780
11	17	37	232	660	1250
12	11	34	278	780	1880
13	13	33	269	89	2000
14	13	30	243	820	2200
15	13	30	301	1120	2880
16	12	29	278	820	1970
17	11	29	279	980	2230
18	12	28	255	740	1990
19	13	27	272	990	2620
20	13	26	289	880	2430
Mean	13	37	271	890	2100

Table 2. Radiographic measurements in the study group

	Scoliosis curvature (°)				Thoracic kyphosis (°)				Lumbar lordosis (°)				Pelvic obliquity (°)			
Patient	Preop	Immediate postop	2 Years postop	Latest	Preop	Immediate postop	2 Years postop	Latest	Preop	Immediate postop	2 Years postop	Latest	Preop	Immediate postop	2 Years postop	Latest
1	80	8	8	9	23	20	21	21	25	30	28	28	14	5	6	6
2	60	10	10	11	5	18	20	20	10	35	38	38	10	4	6	6
3	72	8	9	10	10	15	16	16	33	30	33	33	8	3	4	4
4	65	10	11	11	5	20	22	22	5	38	40	40	13	8	8	9
5	55	14	13	15	5	18	19	19	39	32	30	30	12	5	6	6
6	70	15	17	16	–7	22	24	24	47	37	38	38	11	6	8	7
7	51	12	13	15	5	12	13	13	0	45	42	42	8	3	5	6
8	81	17	18	20	6	16	18	18	6	36	35	35	14	5	4	5
9	72	15	16	18	–8	20	22	21	58	28	29	29	15	4	4	4
10	71	18	18	19	10	15	18	18	10	33	35	38	13	4	6	6
11	62	10	11	11	22	20	22	20	18	8	8	7	15	3	3	3
12	81	12	14	13	5	17	20	20	55	42	45	44	12	4	4	6
13	78	25	28	27	5	15	17	17	5	35	38	38	10	4	4	5
14	58	18	22	22	13	18	20	20	36	43	40	41	7	3	5	3
15	70	15	16	18	3	20	24	24	13	37	39	39	14	5	6	6
16	85	20	22	23	6	15	17	17	58	46	43	43	15	8	7	8
17	75	15	17	17	11	14	16	16	–6	31	33	34	15	7	8	8
18	68	18	20	22	5	20	18	17	11	45	45	43	12	7	8	8
19	77	18	18	19	20	25	19	19	10	30	32	32	15	6	7	7
20	71	20	21	22	5	28	27	27	6	35	38	38	14	7	8	7
Mean	70	15 (77%)	16	17	7	19	20	20	20	35	36	36	13	5 (62%)	6	6

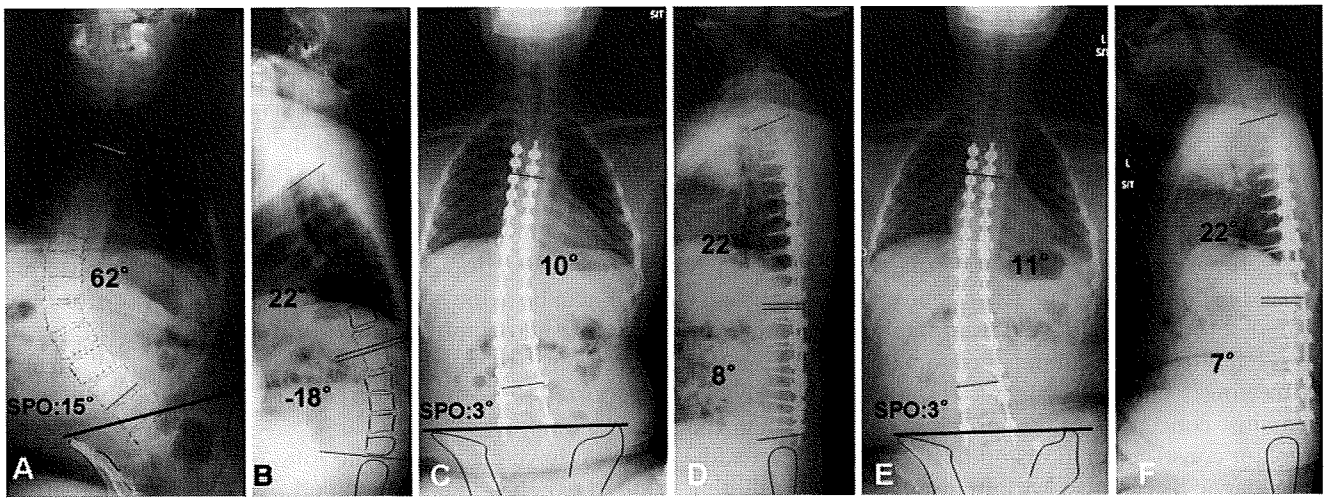

Fig. 2. A, B Radiographs of a 13-year-old boy. Sitting anteroposterior preoperative radiograph demonstrates a significant thoracolumbar curve of 62° from T5 to L4. The pelvic obliquity was 15°. Lumbar kyphosis is present. He reported back pain and difficulty sitting before surgery. **C, D** Postoperative radiographs at 1 week after surgery. Significant initial coronal curve correction was obtained; and the lateral radiograph indicates contouring of the rods, allowing creation of a sagittal profile. The pelvic obliquity improved to 3°. **E, F** Radiographs at a long-term follow-up of 3 years 1 month after surgery demonstrate the lack of progression of deformity and instrumentation failure. Good pelvic balance was maintained. He reported back pain, and sitting was less difficult

patients after surgery. We noted no significant loss of correction of pelvic obliquity.

Only pedicle screws were employed as vertebral anchors in the thoracic and lumbar spine. A total of 468 screws were placed safely in the 20 patients, with no reoperations for screw malposition. Fluoroscopy was used to confirm acceptable screw position. Clinically, there were no neurological deficits or radicular symptoms.

All patients reported that difficulty sitting was alleviated after surgery. Also, all patients reported their back pain had diminished after surgery. The mean VAS improved from 6.2 before surgery to 2.5, 1.8, and 1.6 at 6 weeks, 1 year, and 2 years after surgery, respectively.

There were five postoperative complications, all of which were paralytic ileus, which resolved with observation without oral intake for at least 48 h. There were no neurological complications, instrumentation failures, pull-out of the fixation devices, or infections. There were no reoperations for any reason, nor any second hospitalizations related to the scoliosis surgery.

There was no significant loss of correction in the coronal or sagittal plane at the last follow-up in our series. No patients reported pain, and there were no clinical complaints in the region of surgery at the last follow-up. There was no instrumentation failure. Thus, there was no clinical or radiographic evidence of nonunion in any of the patients.

Figure 2 shows a radiographic example. The sitting anteroposterior preoperative radiograph demonstrates a significant thoracolumbar curve of 62° from T5 to L4 and a pelvic obliquity of 15°. The lateral radiograph demonstrates lumbar kyphosis of 18°. Radiographs immediately after surgery demonstrate significant initial coronal curve correction and significant improvement in the sagittal plane. The pelvic obliquity improved to 3° after surgery. A balanced spine in the coronal and sagittal plane was maintained at 3 years 1 month after surgery.

Discussion

To our knowledge, this study is the only reported series of consecutive cases of scoliosis secondary to DMD treated with segmental pedicle screw instrumentation and fusion to L5. Excellent minimum 2-year results are shown in this study, with no reoperations for nonunion, infection, or instrumentation failure. Radiographically, there was 77% coronal curve correction, normalization of the sagittal plane, and 62% correction of pelvic obliquity. Loss of correction was minimal. The largest coronal curve size and the highest pelvic obliquities in this study were 85° and 15°, respectively. Thus, with the results of this study, segmental pedicle screw instrumentation and fusion only to L5 was safe and effective in patients with DMD scoliosis of <85° and pelvic obliquity of <15°.

For the treatment of spinal deformity in DMD, strong anchors are needed because of the increased loss of muscular stability, which causes asymmetrical muscle balance, leading to progression of spinal deformity[12,16] and because of osteopenia in this population.[12,17,18] The

superior biomechanical advantages of pedicle screws over other forms of spinal bone–implant interfaces allow the correction technique to generate powerful corrective forces in all planes. Segmental pedicle screw instrumentation has been also reported to offer significant coronal and sagittal curve correction and maintenance of correction in patients with adolescent idiopathic scoliosis.[19,20]

Instrumentation and fusion to the sacrum/pelvis has been a mainstay in the treatment of neuromuscular spinal deformity since the development of the intrailiac post, and it is recommended for preventing and/or correcting pelvic obliquity.[5,15] However, controversy remains concerning the necessity of extending the implant constructs and fusion to the pelvis.[10–12] In addition, pelvic fixation has certain disadvantages, including increased blood loss, longer operating time, and technical difficulty.[4,20–22] Also, the sacrum and pelvis in patients with DMD are often small and osteoporotic.[7,23] Although suprapelvic fusion has shown greater loss of long-term correction, especially of pelvic obliquity, there is growing evidence that adequate correction can be obtained and maintained by fusion to the distal lumbar spine or even short-segment anterior instrumentation.[8,12,24]

The lumbosacral articulation is normally a highly stable joint secondary to traction exerted by the iliolumbar ligament and stability imparted by annulus fibrosis and the anterior longitudinal ligament.[25] Therefore, with stable lumbosacral articulation, pedicle screw instrumentation into L5 should allow correction of pelvic obliquity.[10] Pelvic obliquity was due to the suprapelvic effects of scoliosis. In addition, addressing the spinal deformity has been shown to correct pelvic obliquity effectively. Frischut et al.[26] found pelvic obliquity was effectively corrected by correcting the spinal deformity. Wild et al.[27] noted spontaneous correction of pelvic obliquity after the spinal deformity was adequately addressed. In our series, scoliosis was adequately addressed after surgery and maintained long term; moreover, the pelvic obliquity was effectively corrected and maintained.

The advantage of the mobile L5/S1 disc space includes absorption of much of the angular and rotational movement of the trunk during wheelchair activities. The presence of mobility of L5/S1 may assist in sitting and transfer activities.

Most studies on scoliosis surgery in patients with DMD have dealt with spinal instrumentation using hooks, wires, or hybrid constructs with pedicle screws in the lumbar spine. These spinal instrumentation systems have shown poor long-term results for both correction of the scoliotic curvature and the pelvic obliquity.[10–12] There are few studies on the use of pedicle-screws-alone fixation for DMD scoliosis. Hahn et al.[23] reported excellent results for the coronal deformity with 77% correction initially and long term using pedicle-screw-alone fixation to the pelvis (not segmental pedicle screw instrumentation). The mean preoperative curve size in that study was 44°. They reported 78% initial correction of pelvic obliquity and 80% final correction. Modi et al.[28] reported that in patients with neuromuscular scoliosis (including 10 with DMD scoliosis), acceptable amounts of curve correction (a mean of 61% initial correction and 58% correction at the last follow-up) can be achieved and maintained with posterior-only pedicle screw instrumentation to the pelvis. The mean preoperative curve size in that study was 79°. They reported 45% initial correction of pelvic obliquity and 47% final correction.

We have challenged the long-term belief that fusion to the pelvis can be avoided even in nonambulatory patients with DMD. In our series, excellent coronal correction as well as good pelvic balance was achieved and maintained despite fusion only to L5. With the results of our study, segmental pedicle screw instrumentation and fusion only to L5 appears to be equivalent to that with fusion to the sacrum/pelvis for correction of scoliotic curvature and pelvic obliquity both initially and during long-term correction.

Sagittal plane alignment was well recreated in our series. Correction of thoracic hypokyphosis was found, with a preoperative mean of 7° to a postoperative mean of 19°. With a postoperative mean of 36°, an excellent reconstruction of lumbar lordosis was achieved in all of our patients. The change in the sagittal plane alignment reflected the intention to recreate a good sagittal profile. Adequate lumbar lordosis is important for good and balanced sitting by patients with DMD, in whom flexion contractures of the hips and knees are often present.

There has been no quality of life (QOL) measure appropriate for DMD scoliosis patients. Therefore, this study did not use an outcome instrument. However, all of our patients reported that their difficulty sitting had diminished and back pain decreased after surgery even though all patients reported difficulty sitting and back pain before surgery. Thus, this study shows our patients benefited from scoliosis surgery in terms of spinal deformity correction, pelvic obliquity correction, improved sitting, and decreased back pain.

Study limitations

There are several limitations in this study. There was no randomized control group. In this study of 20 consecutive patients, all had DMD scoliosis of <85° and pelvic obliquity of <15° preoperatively. Therefore, it remains to be elucidated whether the same conclusions apply to the DMD scoliosis of greater curve degrees with greater pelvic obliquity. Radiological assessment of fusion is

never perfect. Determination of fusion has been a difficult issue, with no methods having been shown to be reliable. A definition that combined radiographic minimal loss of correction with no clinical complaints was selected for this series. Although segmental pedicle screw instrumentation is stable and can mask pseudarthroses during the first few years, the lack of progression of deformity, the absence of instrumentation failure, and no clinical complaints with a minimum follow-up of 2 years indicate the probability of the absence of pseudarthrosis.

Conclusion

Segmental pedicle screw instrumentation ending at L5 offered the ability to correct spinal deformity and pelvic obliquity initially, at the intermediate term, and even long term, with no major complications. Segmental pedicle screw instrumentation and fusion only to L5 is safe and effective in patients with DMD scoliosis of <85° and pelvic obliquity of <15°. All patients benefited from surgery in terms of improved QOL. This method in appropriate patients can be a viable alternative to instrumentation and fusion of the sacrum/pelvis.

No benefits in any form have been or will be received from a commercial party related directly or indirectly to the subject of this manuscript.

References

1. Marsh A, Edge G, Lehovsky J. Spinal fusion in patients with Duchenne muscular dystrophy and a low forced vital capacity. Eur Spine J 2003;12:507–12.
2. Askin GN, Hallettv R, Hare N, Webb JK. The outcome of scoliosis surgery in the severely handicapped child: an objective and subjective assessment. Spine 1997;22:44–50.
3. Hsu JD. The natural history of spinal curve progression in the nonambulatory Duchenne muscular dystrophy patient. Spine 1983;8:771–5.
4. Benson ER, Thomson JD, Smith BG, Banta JV. Results and morbidity in a consecutive series of patients undergoing spinal fusion for neuromuscular scoliosis. Spine 1998;23:2308–17.
5. Dias RC, Miller F, Dabney K, Lipton G, Thomas TT. Surgical correction of spinal deformity using a unit rod in children with cerebral palsy. J Pediatr Orthop 1996;16:734–40.
6. Galasko CBS, Delany C, Morris P. Spinal stabilisation in Duchenne muscular dystrophy. J Bone Joint Surg Br 1992;74:210–20.
7. Bell DF, Moseley CF, Koreska J. Unit rod segmental spinal instrumentation in the management of patients with progressive neuromuscular spinal deformity. Spine 1989;14:1301–7.
8. Gaine WJ, Lim J, Stephenson W, Galasko CBS. Progression of scoliosis after spinal fusion in Duchenne muscular dystrophy. J Bone Joint Surg Br 2004;86:550–5.
9. Heller KD, Wirtz DC, Siebert CH, Forst R. Spinal stabilization in Duchenne muscular dystrophy: principles of treatment and record of 31 operative treated cases. J Pediatr Orthop B 2001; 10:18–24.
10. McCall RE, Hayes B. Long-term outcome in neuromuscular scoliosis fused only to lumbar 5. Spine 2005;30:2056–60.
11. Sengupta DK, Mehdian SH, McConnell JR, Eisenstein SM, Webb JK. Pelvic or lumbar fixation for the surgical management of scoliosis in Duchenne muscular dystrophy. Spine 2002;27: 2072–9.
12. Whitacker C, Burton D, Asher M. Treatment of selected neuromuscular patients with posterior instrumentation and arthrodesis ending with pedicle screw anchorage. Spine 2000;25:2312–8.
13. Allen B Jr, Ferguson R. The Galveston technique for L rod instrumentation of the scoliotic spine. Spine 1982;10:276–84.
14. Mubarak SJ, Morin WD, Leach J. Spinal fusion in Duchenne muscular dystrophy: fixation and fusion to the sacropelvis? J Pediatr Orthop 1993;13:752–7.
15. Sussman MD. Advantage of early spinal stabilization and fusion in patients with Duchenne muscular dystrophy. J Pediatr Orthop 1984;4:532–7.
16. Daher Y, Lonstein J, Winter R, Bradford D. Spinal surgery in spinal muscular atrophy. J Pediatr Orthop 1985;5:391–5.
17. Bentley G, Haddad F, Bull TM, Seingry D. The treatment of scoliosis in muscular dystrophy using modified Luque and Harrington-Luque instrumentation. J Bone Joint Surg Br 2001; 83:22–8.
18. McCord DH, Cunningham BW, Shono Y, Myers JJ, McAfee PC. Biomechanical analysis of lumbosacral fixation. Spine 1992;17: S235–43.
19. Lowenstein JE, Matsumoto H, Vitale MG, Weidenbaum M, Gomez JA, Lee FY, et al. Coronal and sagittal plane correction in adolescent idiopathic scoliosis: a comparison between all pedicle screw versus hybrid thoracic hook lumbar screw constructs. Spine 2007;32:448–52.
20. Suk SI, Lee CK, Kim WJ, Chung YJ, Park YB. Segmental pedicle screw fixation in the treatment of adolescent idiopathic scoliosis. Spine 1995;20:1399–405.
21. Miladi LT, Ghanem TB, Draui MM, Zeller RD, Dubousset JF. Iliosacral screw fixation for pelvic obliquity in neuromuscular scoliosis. Spine 1997;22:1722–9.
22. Schoenfelder K, Cheng CL, Hsu LCS. Pelvic obliquity in poliomyelitic scoliosis: correction of pelvic obliquity without fusion to the sacrum. Orthop Trans 1987;32:333–40
23. Hahn F, Hauser D, Espinosa N, Blumenthal S, Min K. Scoliosis correction with pedicle screws in Duchenne muscular dystrophy. Eur Spine J 2005;17:255–61
24. Basobas L, Mardjerko S, Hammerberg K, Lubicky J. Selective anterior fusion and instrumentation for the treatment of neuromuscular scoliosis. Spine 2003;28:S245–8.
25. Luk KD, Ho HC, Leong JC. Iliolumbar ligament. J Bone Joint Surg Br 1986;68:197–200.
26. Frischut B, Krismer M, Stoeckl B. Pelvic tilt in neuromuscular disorders. J Paediatr Orthop B 2000;9:221–8.
27. Wild A, Haak A, Kumar M. Is sacral instrumentation mandatory neuromuscular thoracolumbar scoliosis due to myelomeningocele? Spine 2001;26:E325–9.
28. Modi HN, Suh SW, Song HR, Fernandez HM, Yang JH. Treatment of neuromuscular scoliosis with posterior-only pedicle screw fixation. J Orthop Surg 2008;3:23.

3．胸椎後縦靭帯骨化症と後弯

胸椎後縦靭帯骨化症に対する後方除圧固定術*

後弯矯正および脊髄症改善の機序を中心に

山崎 正志**

はじめに

[1] 後方除圧固定術導入の経緯

胸椎後縦靭帯骨化（ossification of posterior longitudinal ligament；OPLL）に伴う脊髄症例に対し，われわれは後方除圧術（椎弓切除術および頸胸椎椎弓形成術）および骨化摘出術（前方除圧固定術および後方進入脊髄前方除圧術）の二本立てで手術治療を行ってきた．これまでの過程で，術直後に脊髄症状悪化をきたした症例の解析から，術前の下肢機能が独歩不能のレベルまで低下している脊髄重度障害例では，骨化摘出が危険であることを認識した[2]．さらに，われわれは一過性の術後悪化を2例で経験した．この2例では椎弓切除術後に症状が悪化し，後方instrumentation固定の追加で麻痺が改善した[3,4]．この経験からわれわれは，骨化を摘出しなくとも後方instrumentation固定を行うことにより，ある程度の症状改善が期待できるのではという仮説を立てた．そして，後方除圧固定術（椎弓切除＋後方instrumentation固定）を術前脊髄重度障害例，骨化摘出が困難な例に対して導入し施行してきた[5~11]．

Key words
胸髄症（thoracic myelopathy）
後縦靭帯骨化症
（ossification of posterior longitudinal ligament）
後弯（kyphosis）

[2] 術式の概念

われわれは後方除圧固定術を行うにあたり，Kawaharaら[1]が報告している脊髄全周除圧術と同じ概念で手術を計画した[6]．すなわち，後方除圧固定術を行ううえでのインフォームド・コンセントでは，初回手術で後方除圧固定術を行い，症状の改善が不十分な場合は前方除圧固定を追加するという説明を行った．したがって，導入当初われわれは，後方除圧固定術を1つの独立した術式としては認識しておらず，あくまで脊髄全周除圧術のうち前方除圧固定が行われなかった場合の術式として評価してきた．

[3] 術式確立のために解明すべき課題

今回は，これまでに行った後方除圧固定術の術後成績を調査し，以下の3項目について検討した．①改善不良例に対して前方からの骨化摘出の追加手術を行うとすれば，時期的に術後のどの時点が望ましいか，②手術の安全性として，術後麻痺の可能性はどの程度あるのか，③術式選択における後方除圧固定術の位置づけとして，これまでのように，あくまで脊髄全周除圧術の一部分手術として捉えるべきか，あるいは，胸椎OPLLに対する

* Posterior Decompression and Instrumented Fusion for Thoracic Myelopathy due to Ossification of the Posterior Longitudinal Ligament：Correction of Kyphosis and Mechanisms for the Improvement of Myelopathy

** 千葉大学大学院医学研究院整形外科学〔〒260-8677 千葉市中央区亥鼻1-8-1〕／Masashi YAMAZAKI：Department of Orthopaedic Surgery, Chiba University Graduate School of Medicine

0914-4412/09/¥400/論文/JCLS

独立した術式として認識してよいかである．

対象および方法

1 後方除圧固定術の術式

1．後方除圧および固定範囲の決定

術前の画像所見で，脊髄後方のくも膜下腔が消失している高位は，後方除圧の範囲に含める．固定アンカーに関して当初はフックを用いていたが，最近では大部分の例で椎弓根スクリュー（pedicle screw；PS）を使用している．通常，頭側の3椎体，尾側の3椎体にPSを刺入しアンカーとしている．

2．手術体位

頸椎病変を伴う例ではいうまでもないが，胸椎部の病変のみの例でも必ずMayfield three pinにて頭部を固定し，胸椎のalignmentに注意して体位をとる．当初は，胸椎後弯を矯正するようにして体位をとっていた．しかし，症例によっては術前，体位によって脊髄症が増悪する例があり（症例2），後方除圧を行う前の無理な後弯矯正は，時として危険であることを認識した．

3．展開とPS刺入

椎弓切除を行う前に，PSを刺入する．これは，椎弓切除後に，なるべく早くロッドを設置し，脊椎固定を済ませたいという考えからである．椎弓切除を行うと後方支持要素がなくなることから，胸椎のalignmentが変化する可能性がある．したがって，脊髄への影響を少しでも減らすためには，椎弓切除後，できるだけ短時間のうちにロッド設置に移る．

4．後方除圧

最狭窄部では通常，脊髄はOPLLと黄色靭帯骨化（ossification of yellow ligament；OYL）で前後から狭窄されている．この部の脊髄は，扁平化が著しいうえに逃げ場がない．さらに，ほとんどの例で硬膜とOYLが癒着している．椎弓切除を行うにあたっては，椎弓内板の皮質骨を開削する際，および硬膜からOYLを剝離する際に脊髄を障害しないよう注意する．頭尾側での除圧が十分かどうかは，術中超音波診断にて確認する．

5．instrumentation 装着

脊髄の後方除圧を確認後にロッドを装着する．基本的に後弯の矯正は行わず，*in situ* の固定とする．骨移植には採取した棘突起を用い，椎弓上および横突起間に移植する．術式の詳細および注意点については，筆者のこれまでの報告を参照されたい[12,13]．

2 手術症例

1989年5月～2004年10月までの期間に，千葉大学医学部附属病院および関連施設で，胸椎OPLLに伴う脊髄症に対し後方除圧固定術を行い，術後1年以上が経過した24例を対象とした．内訳は，男7例，女17例．年齢は平均54.8歳（32～74歳）．術後経過観察期間は平均4年5カ月（1～12年10カ月）であった．術後成績は，日本整形外科学会頸髄症治療判定基準から上肢項目を除いた11点満点（以下，日整会点数）で評価し，改善率を平林法で算出した．術前，術後3，6，9，12カ月および最終調査時に評価を行った．

結果および考察

1 術後成績

日整会点数は，術前平均3.7（1～6.5）点が術後最終調査時で平均8.0（4～11）点，改善率は最終調査時で平均58.1（10～100）％であった．日整会点数の推移は，術後3カ月で平均6.4点，術後6カ月で平均7.3点，術後9カ月で平均7.7点，術後12カ月で平均7.9点であった（図1）．改善率の推移は，術後3カ月で平均36.7%，術後6カ月で平均48.8%，術後9カ月で平均54.0%，術後12カ月で平均56.8%であった（図1）．症例ごとの日整会点数の推移を解析すると，点数がピークに達した時期は，術後3カ月～2年で，平均は術後9.5カ月であった（図1）．前方からの骨化摘出の追加手術を希望した例はなかった．

2 骨化摘出の追加手術の時期

今回調査した後方除圧固定術の成績は改善率が平均58.1%であった．われわれのこれまでの調