Correction of pelvic obliquity in neuromuscular spinal deformities using the “T construct”: results and complications in a prospective series of 60 patients

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Received: 23 December 2012 / Revised: 21 April 2013 / Accepted: 1 June 2013 / Published online: 17 July 2013
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Abstract

Background We present the results of a prospective series of 60 patients treated for neuromuscular spinal deformities with an original spinopelvic construct using two sacral screws and two iliac screws. Clinical and radiological results obtained with this new surgical technique were studied and discussed according to the epidemiological data and relevant literature.

Methods From January 2008 to June 2010, the clinical data of every patient who underwent spinopelvic fixation for treatment of a neuromuscular spinal deformity were recorded prospectively.

Results Sixty patients were operated on during the study period. Spinal correction and fusion was performed by posterior approach. In six patients with a residual spinopelvic imbalance more than 15° on lateral preoperative bending films, an anterior release of the thoracolumbar junction was performed on the same day, before posterior correction. Preoperative pelvic obliquity (PO) ranged from 4° to 44° (mean 21.6°). Postoperative pelvic obliquity ranged from 0° to 14 (mean 4.6°). No significant loss of correction was noted at the last follow-up. One patient died 3 months after the initial procedure due to respiratory compromise. 11 patients had early postoperative infections of the posterior approach.

Conclusions Despite a high rate of infectious complications, optimal correction of pelvic obliquity requires extension of spinal instrumentation to the pelvis. Spinopelvic

fixation remains a difficult challenge in neurological patients with hypotrophy. We think that pelvic fixation with the “T construct” did provide effective and improved spinal stabilization in these patients, while reducing the need for a postoperative cast or brace. As a result, patients had a favourable postoperative course with early mobilization and return to a comfortable sitting position.

Keywords Neuromuscular scoliosis · Pelvic obliquity · Pelvic imbalance · Surgery · T construct

Introduction

Spinal deformity is common in children and adolescents with neuromuscular disorders. Incidence is higher than 20–25 % in nonambulatory patients and total-body cerebral palsy (CP) patients [1, 2]. Scoliosis with pelvic obliquity (PO) is the most common deformity especially in patients with trunk hypotonia and quadriplegia. The development of a severe trunk deformity associated with the inherent neurological disorder can significantly restrict the patients' functional capacities and maximize the need for nursing care [3]. Sitting tolerance may be increasingly diminished and trunk decompensation can result in back or rib impingement pain, as well as pulmonary complications [4]. Such patients often require a long fusion from the upper thoracic spine to the sacrum or pelvis to achieve and maintain correction of the curve and the PO. Modern techniques of pelvic fixation include sacral screws [5], sacral plates, CD-Galveston [6–8], and iliosacral screws [9–11]. We present the results of a prospective series of 60 patients treated for neuromuscular spinal deformities with an original spinopelvic construct using two sacral and two iliac screws. The aims of this study were to assess the management of a large series of

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neuromuscular spine deformities in children and adolescents treated with a new technique of pelvic anchorage and a new strategy of PO correction at one center. We reviewed the results of treatment of the deformity, as well as the complications at follow-up.

Materials and methods

From January 2008 to June 2010, all the patients undergoing a spinopelvic fixation for a neuromuscular spinal deformity were prospectively included in a computerized database. Demographical data included the age and etiology of neuromuscular disorder. Radiographical data included the extend and severity of spinal deformities and measurements of Cobb angles, T4T12 thoracic kyphosis and L1L5 lumbar lordosis, Cobb angle reducibility on bending films. PO was measured with the “Pelvic frontal obliquity angle” described and used in a previous paper [12] (Fig. 1). Intraoperative time and bleeding were noted. Postoperative radiological data included the same angular measurements. The spinal and spinopelvic fusion was assessed at final follow-up by the absence of back pain with no loss of correction. During follow-up, mechanical and infectious complications were prospectively noted. The minimal follow-up was 30 months to assess spinal fusion. The data were analyzed using SPSS 16 software (IBM Corporation, 1 New Orchard Road Armonk, New York 10504-1722, USA). The data were tested regarding its normality and paired comparisons of means were done using a paired *T* test. $P < 0.05$ was considered as being significant.

Results

60 patients were operated on during the inclusion period. All patients were operated on by a senior surgeon including the same senior author. 21 patients were diagnosed with spinal muscular atrophy (SMA) (9 patients with type 1b SMA and 12 patients with type 2 SMA), 14 patients had Duchenne’s muscular dystrophy and 8 patients had other congenital muscular dystrophy. 14 patients had cerebral palsy, 3 patients had flacid congenital paraplegia (myelomeningocele) and 2 patients had flacid post-traumatic paraplegia. Mean age was 13.3 years (10–19 years). Spinal deformity was a thoracolumbar curve in 32 cases, a lumbosacral curve in 14 cases, a lumbar curve in 4 cases and a combined thoracic and lumbar curve in 10 cases.

Spinal correction and fusion was performed by posterior approach. 13 patients with a stiff and severe deformity had a preoperative halo-traction period during 4–6 weeks. In six patients with a residual spinopelvic imbalance more

Fig. 1 The “Pelvic frontal obliquity angle” was measured between the line perpendicular to the bisacroiliac line and the line between the spinous process of T1 and the middle of the sacroiliac line

than 15° on lateral preoperative bending films, an anterior release of the thoracolumbar junction was performed on the same day, before posterior correction. Posterior correction was performed using pedicular screws from T4 to L4 and two pediculo-laminar clamps (pedicular and laminar hooks) to fix at the upper thoracic spine (XiaTM instrumentation System, Stryker Europe, Cite-Centre Grand-Rue 92, P.O. Box 1568, 1820 Montreux, Switzerland). 38 patients with a body weight lower than 35 kg were operated on using two 4.5 mm diameter Vitalium (Cobalt chromium) rods (Fig. 2). The 22 remaining patients with a body weight equal or upper than 35 kg were operated on using two 6 mm diameter Vitalium (Cobalt chromium) rods (Fig. 3). Each time, pelvic anchorage was made with an original segmental construct. Two sacral and two iliac screws were linked together by means of an horizontal 4.5 mm titanium rod. The pelvic construct was then linked to the spinal rods by means of two 90° long-offset connectors. It was mandatory not to place L5 pedicle screws to

Fig. 2 Example of correction using the “T-construct” using two 4.5 mm diameter Vitalium rods in a congenital muscular dystrophy patient. Pelvic instrumentation was made of two sacral screws and to standard pedicular screws placed into the iliac wings. The four pelvic

implants were linked together with the horizontal bar and two 90° rods-connectors were used to link the pelvic anchorage with the spinal instrumentation **a** preoperative full-spine frontal radiograph. **b** Post-operative result with minimal residual PO

avoid hardware impingement when linking together the spinal and pelvic constructs with the help of parallel cross-connectors. After linking together the spinal and pelvic constructs, PO was corrected stepwise after main spinal curve correction, doing distraction and contraction maneuvers between the spinal and the pelvic construct (Fig. 4). Surgical technique was previously reported as a technical note and preliminary results in 2011 [13].

At the end of the procedure, spinal fusion was obtained for all the patients by application of autologous bone graft harvested on spinous processes and a biocompatible, osteoconductive scaffold made of hydroxyapatite and beta-tricalcium phosphate (B-TCP) Bone’X (Scient’x, 1015 Maitland Center Commons Suite 106A, Maitland, FL 32751, USA).

Patients body weight ranged from 17 to 95 kg (mean 34 kg). Preoperative Cobb angle ranged from 0° (pure lumbar hyperlordosis and/or thoracic hyperkyphosis) to 142° (mean 70.4°). Preoperative PO ranged from 4° to 44° (mean 21.6°). Preoperative lumbar lordosis ranged from –28° (i.e. a 28° lumbar kyphosis) and 91° (mean 28.3°).

Preoperative thoracic kyphosis ranged from –5° (i.e. a 5° thoracic lordosis) and 80° (mean 21°). Preoperative main Cobb angle reducibility on bending films ranged from 0° to 119° (mean 54.23°).

Mean operative time was 219 min (160–380 min) including the anterior release time in six patients. Mean estimated blood loss was 816 ml (285–2,200 ml). Postoperative Cobb angle ranged from 0° to 85° (mean 28.1°). Postoperative PO ranged from 0° to 14° (mean 4.6°). Preoperative lumbar lordosis ranged from 0° and 73° (mean 33°). Preoperative thoracic kyphosis ranged from 0° and 80° (mean 18°). Detailed epidemiological results are presented in Table 1.

Statistical analysis of paired means values showed a statistically significant relationship between patient weight and intraoperative time ($R = 0.274$ and $P = 0.034$) and between patient weight and intraoperative bleeding ($R = 0.442$ and $P < 0.0001$). A statistically significant correlation existed between patients age and intraoperative bleeding ($R = 0.361$ and $P = 0.005$). Regarding the correction of PO, the quality of the correction was

Fig. 3 Example of correction using the “T-construct” using two 6 mm diameter Vitalium rods in a CP patient. **a** Preoperative full-spine frontal radiograph. **b** Post-operative result with complete PO correction

significantly related to a longer intraoperative time ($R = 0.285$ and $P = 0.027$). Regarding the correction of the lumbar lordosis, the importance of the correction was significantly related to an increase of intraoperative bleeding ($R = 0.299$ and $P = 0.020$) and intraoperative time ($R = 0.328$ and $P = 0.010$). The details of statistical study are presented in Table 2. Mean follow-up duration was 49 months (from 30 to 60 months). No additional bracing was needed after surgery except for nine patients with type 1b SMA requiring a specific postoperative brace to support the head. No delayed fusion, pseudoarthrosis, implant failure or loss of correction was noted at final follow-up.

Complications

One patient died 3 months after the initial procedure due to respiratory compromise. 11 patients had early postoperative infections of the posterior approach. Outcome was favourable in ten cases after re-operation, local wound

debridement and antibiotics. In one case, hardware removal was done after 1 year due to persistent chronic infection with *Morganella* sp. Outcome was favourable in this patient with satisfactory healing, no recurrence of infection and no loss of correction following hardware removal. No patient was lost to follow-up. The details of postoperative complications are presented in Table 3.

Discussion

PO is commonly associated with scoliosis in cerebral palsy making sitting difficult and needs to be considered during spinal deformity management [13]. PO correction requires extension of spinal instrumentation to the pelvis. One of the technical challenges of posterior spinal fusion in neuromuscular patients is the anchorage of long constructs to the sacropelvic area [14–16]. The Galveston technique of pelvic fixation, which impacts rods between the tables of the ilium, has been the standard [8]. With the growing

Fig. 4 The different consecutive steps of spinopelvic instrumentation with the “T-construct” in a long right thoraco-lumbo-sacral curve with pelvic obliquity (**a**). The thoracolumbar spine is instrumented and corrected by the use of multilevel pedicular screws (**b**). Note pelvic instrumentation made of two sacral screws and two long pedicular screws placed into the iliac wings (**b**). The four pelvic implants are linked together with the horizontal bar (**c**) and two 90° rods-connectors are used to link the pelvic anchorage with the spinal instrumentation (**d**). Corrective maneuvers are applied on the pelvis to achieve final frontal correction (**d**)

popularity of pedicle screw fixation for idiopathic scoliosis correction, similar constructs have begun being used in neuromuscular curves [17]. Miladi, Zeller and Dubousset reported the first experience of ilio-sacral screw fixation for spino-pelvic imbalance in neuromuscular patients in 1996 [10]. In such indications, we experienced technical difficulties due to the size of ilio-sacral screws and connectors especially in hypotrophic patients [9]. In patients with a body weight lower than 35 kg, we decided to use a specific “paediatric” spinal instrumentation with a 4.5 titanium rod instead of conventional 5.5 mm or 6 mm instrumentations. Because no ilio-sacral instrumentation was available with this “paediatric” instrumentation, we decided to promote this original segmental ilio-sacral construct [13].

Our results in this wide prospective cohort of patients are similar with those obtained with other techniques (ilio-sacral screws, Luque–Galvestone technique or iliac extension screws) as shown in Table 4. In our technique, PO correction was achieved in good position and no loss of correction was noted at final follow-up. Limited postoperative loss of PO correction was reported after spinopelvic fixation using other techniques as summarized in Table 4. In Luque technique [18–20], the authors documented a vertical dissociation of the Luque rods. When fusion occurs in the instrumented spine with recurrent PO, it results in a permanently unbalanced spine with difficulty in seating.

Many difficulties may be encountered in pelvic fixation especially in osteoporotic patients. The Galveston

Table 1 Descriptive study of the data

	<i>N</i>	Minimum	Maximum	Mean	SD
Body weight (kg)	60	17.00	95.00	34.03	14.91
Age (years)	60	10.00	19.00	13.37	2.26
Preoperative Cobb angle (°)	60	0.00	142.00	70.47	32.14
Preoperative pelvic obliquity (°)	60	4.00	44.00	21.67	10.97
Preoperative lumbar lordosis (°)	60	−28.00	91.00	28.38	29.64
Preoperative thoracic kyphosis (°)	60	−5.00	80.00	21.07	18.43
Preoperative Cobb angle reducibility (°)	60	0.00	119.00	54.23	24.37
Intraoperative time (min)	60	160.00	380.00	219.50	43.67
Intraoperative bleeding (ml)	60	285.00	2,200.00	816.72	508.56
Postoperative Cobb angle (°)	60	0.00	85.00	28.12	20.43
Cobb angle gain (°)	60	0.00	94.00	41.92	21.62
Postoperative pelvic obliquity (°)	60	0.00	14.00	4.63	3.60
Pelvic obliquity gain (°)	60	1.00	40.00	16.58	9.53
Postoperative lumbar lordosis (°)	60	0.00	73.00	33.00	15.86
Lumbar lordosis gain (°)	60	−60.00	52.00	−4.70	25.47
Postoperative thoracic kyphosis (°)	60	0.00	80.00	18.33	14.19
Thoracic kyphosis gain (°)	60	−43.00	31.00	−2.58	16.26

Table 2 Details of statistical mean correlation study

Relation tested	<i>N</i>	Correlation	<i>P</i>	Significance
Body weight and preoperative Cobb angle	60	−0.193	0.140	NS
Body weight and preoperative pelvic obliquity	60	−0.207	0.113	NS
Body weight and preoperative lumbar lordosis	60	−0.044	0.736	NS
Body weight and preoperative thoracic kyphosis	60	−0.067	0.611	NS
Body weight and intraoperative time	60	0.274	0.034	Significant
Body weight and intraoperative bleeding	60	0.442	0.000	Significant
Age and preoperative Cobb angle	60	−0.113	0.389	NS
Age and preoperative pelvic obliquity	60	−0.043	0.742	NS
Age and preoperative lumbar lordosis	60	0.234	0.072	NS
Age and preoperative thoracic kyphosis	60	−0.155	0.236	NS
Age and intraoperative time	60	0.194	0.137	NS
Age and intraoperative bleeding	60	0.361	0.005	Significant
Gain of Cobb angle and intraoperative bleeding	60	0.039	0.767	NS
Gain of Cobb angle and intraoperative time	60	0.085	0.520	NS
Gain of Cobb angle and body weight	60	−0.154	0.240	NS
Gain of Cobb angle and age	60	−0.083	0.529	NS
Gain of pelvic obliquity angle and intraoperative bleeding	60	0.185	0.158	NS
Gain of pelvic obliquity angle and intraoperative time	60	0.285	0.027	Significant
Gain of pelvic obliquity angle and age	60	0.077	0.558	NS
Gain of pelvic obliquity angle and body weight	60	−0.139	0.289	NS
Gain of lumbar lordosis and intraoperative bleeding	60	0.299	0.020	Significant
Gain of lumbar lordosis and intraoperative time	60	0.328	0.010	Significant
Gain of lumbar lordosis and age	60	0.249	0.055	NS
Gain of lumbar lordosis and body weight	60	−0.115	0.384	NS
Gain of thoracic kyphosis and intraoperative bleeding	60	0.068	0.605	NS
Gain of thoracic kyphosis and intraoperative time	60	0.021	0.872	NS
Gain of thoracic kyphosis and age	60	0.159	0.225	NS
Gain of thoracic kyphosis and body weight	60	0.042	0.753	NS

Table 3 Details regarding postoperative complications

Patient no.	Gender	Age	Etiology	Body weight (kg)	Preoperative Cobb angle (°)	Cobb angle preoperative flexibility (°)	Preoperative pelvic obliquity (°)	Intraoperative time (min)	Intraoperative bleeding (ml)	Postoperative Cobb angle (°)	Postoperative pelvic obliquity (°)	Complication	Outcome
1	M	16	Duchenne muscular dystrophy	95	26	16	12	280	2,100	9	4	Early infection (<i>Escherichia coli</i>)	Hardware removal/favourable without loss of correction
2	F	13.8	Myelomeningocele	55	26	18	5	290	685	11	2	Early infection (<i>Staphylococcus aureus</i>)	Favourable after local detersion and antibiotics
3	M	17.5	Cerebral palsy	31	72	54	34	270	2,200	19	5	Early infection (<i>Klebsiella pneumoniae</i>)/respiratory compromise	Death after 3 months due to respiratory compromise
4	M	16.8	Cerebral palsy	28	55	50	12	220	739	47	3	Early infection (<i>S. aureus</i>)	Favourable after local detersion and antibiotics
5	F	16.9	Cerebral palsy	42	48	37	25	250	1,990	26	8	Early infection (<i>E. coli</i>)	Favourable after local detersion and antibiotics
6	F	11.5	Spinal muscular atrophy	24	75	64	28	200	500	54	11	Early infection (<i>Enterococcus</i> sp.)	Favourable after local detersion and antibiotics
7	M	14.6	Duchenne muscular dystrophy	28	72	52	23	280	1,480	17	1	Early infection (<i>S. aureus</i>)	Favourable after local detersion and antibiotics
8	F	11.8	Spinal muscular atrophy	19	82	46	42	290	450	28	9	Early infection (<i>S. aureus</i>)	Favourable after local detersion and antibiotics
9	M	11.02	Duchenne muscular dystrophy	33.0	24.8	18	4.6	210	638	3.8	2.6	Early infection (<i>S. aureus</i>)	Favourable after local detersion and antibiotics
10	M	13.83	Duchenne muscular dystrophy	28.0	12.4	6	12.2	190	400	4.0	0.5	Early infection (<i>Enterococcus</i> sp.)	Favourable after local detersion and antibiotics
11	M	13.25	Cerebral palsy	26.0	124.4	79	30.0	240	800	54.7	6.9	Early infection (<i>Pseudomonas aeruginosa</i>)	Favourable after local detersion and antibiotics

Table 4 Comparison of relevant series of the literature

First author	Year	Reference number	Number of patients with pelvic fixation	Technique used	Main curve correction (%)	Mean preoperative PO (°)	Mean postoperative PO (°)	Mean PO loss of correction at final follow-up (°)	Infection rate
Tsirikos	2011	2	45	Iliac extension screws	72.6	21.7	3.3	1.5	15 %
Gau	1991	7	68	Luque Galveston	55	17	8	N/A	10 %
Zahi	2010	9	62	Ilio-sacral screws	57	23	4	1.3	17 %
Miladi	1997	10	154	Ilio-sacral screws	63	20.6	5.9	1.7	3.20 %
Vialle	2006	12	51	Ilio-sacral screws	50.3	27.42	5.21	1.58	2 %
Marchesi	1997	20	25	Luque Galveston	74	19.2	5.3	0.9	N/A
Lonstein	2012	21	93	Luque Galveston	54	15	8	1	1.10 %
Tsirikos	2008	25	242	Luque Galveston + unit rod	71	16.7	4.6	N/A	0.40 %
Benson	1998	27	39	Luque Galveston	65	23	6	N/A	6 %
Vialle	2013	Our series	60	T construct	60	21.67	4.63	0	18 %

technique was sometimes responsible for a motion of the pelvic arm of the rod within the cancellous portion of the ilium which can contribute to hardware migration and loosening at the spinopelvic junction [21–23]. In very difficult conditions as in SMA with osteoporotic and hypotrophic patients, a segmental spino-pelvic fixation as for the “T construct” limits placement difficulties of the implants in the pelvic area. The four implants are placed separately without forced manoeuvres and then linked together with a contoured single rod. The corrective forces are applied at the final step of the correction and not directly on the implants but on a block of four implants. We did not note any mobilization of the implants during the correction of PO in our cohort of patients with the “T construct”.

Our series is prospective but we fully acknowledge the potential bias encountered as the use of two different rod diameters and size of implants. However, all patients were operated on using the same procedure by the same senior surgeon. Despite previous studies have documented a high satisfaction rate among parents and caregivers, who appreciate the impact of scoliosis correction on improving level of function and nursing care [3, 24, 25], it was difficult to evaluate functional results in our patients because quality of life and sitting posture issues could not be assessed by objective functional scores, especially in patients presenting with cerebral palsy and severe mental retardation.

Our minimum follow-up of 30 months is rather sufficient to assess the integrity of fusion. Our results are in line with the literature where the pseudarthrosis rate in neuromuscular patients ranges from 1.8 to 15 % [24, 26–28]. However, the use of multiple segmental screw fixation and cobalt–chromium rods in our patients could achieve greater degree of deformity correction and lesser rate of

complications and reoperations due to nonunion, prominent instrumentation or failed pelvic fixation [2].

If the corrective results of PO obtained by a posterior procedure can definitely be improved by the addition of an anterior release [14], we do not recommend thoracolumbar anterior release to minimize the risk of respiratory complications if residual PO on bending films is $<15^\circ$ [12]. Thanks to the powerful T construct and multiple segmental pedicle screw fixation of the spinal curve, an optimal lumbo-pelvic balance could be expected without the need of an anterior release in a vast majority of patients [9].

Despite the high rate of infectious complications in our patients, we stress the importance of treating frontal and sagittal spinal and pelvic imbalance in neuromuscular patients to avoid poor sitting posture, minimizing skin, respiratory, and/or digestive complications. Numerous series in the literature reported an infection rate from 1 to 15 % in neuromuscular patients (Table 4). Our 18 % infection rate, leaves a concern that it may be due in part to the wide tissue dissection at the caudal end of the spine needed to insert the horizontal portion of the “T”. Spino-pelvic fixation remains a difficult challenge in hypotrophic neurologic patients. We think that pelvic fixation using the “T construct” could provide effective and improved spinal stabilization for these patients, as well as reducing the need for a postoperative cast or brace even in patients with poor bone quality. The use of multiple pedicular screws fixation improved curve correction and spinal rigidity. In these conditions, patients had improved postoperative course with earlier mobilization and return to a comfortable sitting position.

Conflict of interest None.

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