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Pressure Mapping as an Outcome Measure for Spinal Surgery in Patients With Myelomeningocele

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Study Design. A retrospective analysis of prospectively collected data on a cohort of 19 myelomeningocele patients undergoing spino-pelvic deformity surgery.

Objective. To examine if greater curve correction with third generation spinal implants correlate with improved pressure distribution and resolution, or prevention of skin ulcerations in myelomeningocele patients.

Summary of Background Data. Children born with myelomeningocele have often complex spino-pelvic deformities leading to skin ulcerations.

Methods. A cohort of 19 consecutive wheelchair dependent patients with myelodisplastic spinal deformities, who underwent spinal surgery, was prospectively followed with regular pressure mappings for a minimum of 2 years. Standard spino-pelvic radiologic measurements were obtained. Sitting pressure mappings were obtained over the study period using the Force Sensitive Applications from Vista Medical (Winnipeg, Manitoba, Canada). Statistical analysis was done using SAS (SAS Institute Inc, Cary, NC). Paired *t*-test and Wilcox on Signed Rank test was used where applicable. Significance was taken to be $P < 0.05$.

Results. Surgery significantly corrected radiographic parameters, specifically, Cobb angle (52%), pelvic obliquity (89%), and to a lesser degree pelvic tilt. Stratifying the data based on fixation type showed that the M-W construct was able to significantly correct pelvic obliquity. While significant changes in radiographic variables were observed after surgery, this was not the case with the various pressure mapping variables. Only minor changes after surgery were observed in the average pressure, maximum pressure, and variable coefficient of pressure. What was observed was an improvement in the overall distribution from anterior/posterior and right/left. While the values only approached statistical significance ($P = 0.053$) for right/left, however, this did not appear to be clinically significant regarding skin ulceration.

Conclusion. Despite significant surgical corrections in radiographic parameters, these resulted in small changes in pressure distributions and do not appear to influence skin ulceration in the myelomeningocele patient. Pressure mapping may not be a useful tool in predicting outcome of spinal surgery. Factors which were proven to influence pressure distribution are the sagittal pelvic orientation and also achieving coronal spine balance.

Key words: myelomeningocele, spine surgery, pressure mapping, radiographic, skin ulceration. **Spine 2009; 34:2679–2685**

Children born with myelomeningocele have often complex spinal and pelvic deformities.[1–3] The more proximal the spinal dysraphism occurs, the greater the likelihood that these patients will develop these deformities and require surgical treatment.[4,5] These deformities can be congenital in origin associated intradural pathologies. However, there are a number of patients who develop these deformities as they lack core muscle control leading to poor trunk control. Scoliosis is the most common deformity found in this patient population, but kyphosis and kyphoscoliosis are also prevalent.[6] The ambulatory status of these patients has been closely correlated with the incidence of scoliosis.[7,8] The size of the curve and the age of the patients at presentation have all been linked to the progression of deformity.[9] Myelomeningocele patients also tend to develop pelvic obliquity which further compounds sitting imbalance. The pathophysiology of their pelvic obliquity is multifactorial. Rigid lumbar scoliosis, hemi-pelvic hypoplasia, or asymmetrical hip dislocation or contractures can all be causes of pelvic obliquity in this patient population.

These complex spinal and pelvic deformities in myelomeningocele patients are thought to be one of the causes of the development of decubitus ulcers. These occur quite frequently in this patient population. Granted that spino-pelvic deformities are thought to contribute to this high incidence, there are a multitude of other factors such as: prolonged sitting time (wheelchair dependant); insensate skin and dysfunctional sphincters which all contribute to the development of pressure sores. Once present, these ulcerations are challenging problems in the best of times and represent a significant source of morbidity.[10,11]

The stated goal of spine surgery in these complex spino-pelvic deformities is to improve patients sitting balance and function.[12–16] Little is known regarding the impact of spinal surgery[13,17] and the resultant sitting weight distribution in these wheelchair-bound patients.[18] The purpose of this study was to determine if so called modern surgical techniques and instrumentation[19–22] has an influence in this patient populations'

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sitting weight distribution, as well as its impact on the presence or resolution of skin ulcerations.

Materials and Methods

All patients at our institution with a diagnosis of myelomeningocele and spinal deformity which were wheel chair bound were followed prospectively with regular pressure mappings since 2003. Only patients who underwent spinal surgery with modern spinal segmental fixation and who had greater that 2 years follow-up were used for this study. These study patients were recruited from Montreal Children's Hospital and the Montreal Shriners Hospital dating back to 2003. An IRB approved research protocol was used and retrospective medical chart reviews, pressure mappings and radiographs of patients were analyzed by an independent surgeon (L.G.).

Clinical Data

A review of the hospital charts, operative reports, and clinical notes were carried out. Data collected included: patient's age, gender, menarche, functional level, presence or absence of pressure sores, intraoperative parameters (operative time, estimated blood loss, complications, levels fused, type of pelvic fixation), postoperative complications, and length of stay. The presence of skin ulceration was documented before surgery and after surgery.

Radiographic Measurements

All radiologic measurements were obtained through upright sitting radiographs. The patients who were not able to sit independently were provided with the just enough lateral support to obtain the radiographs. The decision to measure pelvic obliquity on AP radiographs as described by Maloney *et al*[14] was made. The pelvic obliquity was determined by measuring the angle between the perpendicular of a line across the superior aspect of the iliac crests and a second line drawn from the center of T1 to the center of S1 (Figure 1). Scoliosis, kyphosis and lordosis were measured by the standardized Cobb method.[23] Trunk decompensation was measured by dropping a plumb line from the spinous process of the first thoracic vertebra and measuring the distance from this line to the spinous process of the first sacral vertebra with the iliac crests positioned parallel to the floor. Measurements were obtained before surgery, immediately after surgery and lastly, at follow-up. Preoperative sagittal pelvic parameters such as sacral slope and pelvic tilt were obtained with a simulated leveled pelvis. That is, patients were positioned (tilted) to have both ischiums resting on the chair trying to obtain a parallel beam across the S1 plateau. After surgery sagittal parameters were taken in a natural sitting position assuming pelvic obliquity was corrected. The Risser sign was also documented before surgery and lastly at follow-up.

Pressure Mapping

Pressure mappings were recorded with VERG Inc. Force Sensitive Application on a yearly basis. If a patient underwent surgery, they had additional recordings at 3, 6, and 12 months and then they were returned to yearly recordings. Two types of recordings were taken. One reading was taken in the patient's own wheelchair and the second was taken on a standardized chair with 2 inches of neoprene. Each recording consisted of a 5 minute continuous recording while the patients are sitting unassisted. This allows for averaging of individual pressure cell improving the accuracy of each recording. It also provides an accurate representation of patient's true sitting balance allowing for a reproducible pressure mapping. In addition to the topographic representation of the pressure distribution, the Force Sensitive Application provided an additional 5 parameters. These were: (1) global average pressure, (2) the maximum pressure, (3) the variation coefficient, (4) right to left weight distribution (R/L), and (5) front to back weight distribution (F/B). The variation coefficient was obtained by dividing the standard deviation of each sensor by the average pressure. This parameter told us how evenly distributed the pressure was across the studied surface. The lower the variation coefficient, the more the pressure was distributed evenly (Figure 2).

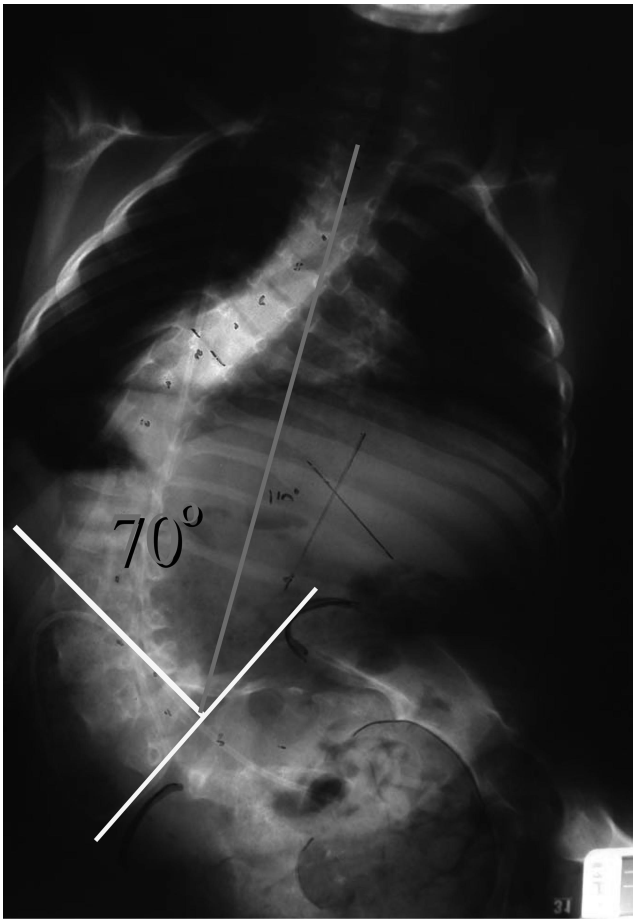


Figure 1. Neuromuscular scoliosis measuring 110° while pelvic obliquity measured 70° as per Malhoney.

Surgical Indications and Technique

Surgical indications comprised of: (1) documentation of a progressive deformity leading to loss of functional status (loss of independent sitting) (2) magnitude of the curves greater than 40° in a skeletally immature patient, or greater than 50° in a skeletally mature person.[5,7,24] All patients had systematic posterior spinal instrumentation and fusion with a staged anterior spinal fusion spanning the dysraphic segments. If patients had a rigid or fixed lumbar scoliosis >70°, then an anterior release and fusion was done first and then followed by the posterior spinal fusion. The rest of the patients had their posterior spinal instrumentation and fusion first, followed by their anterior spinal fusion with tibial strut graft across the dysraphic segment. All patients had segmental instrumentation of the spine with pedicle screws. When pedicle screws were not feasible then laminar hooks or sublaminar wires were used. For the sacro-

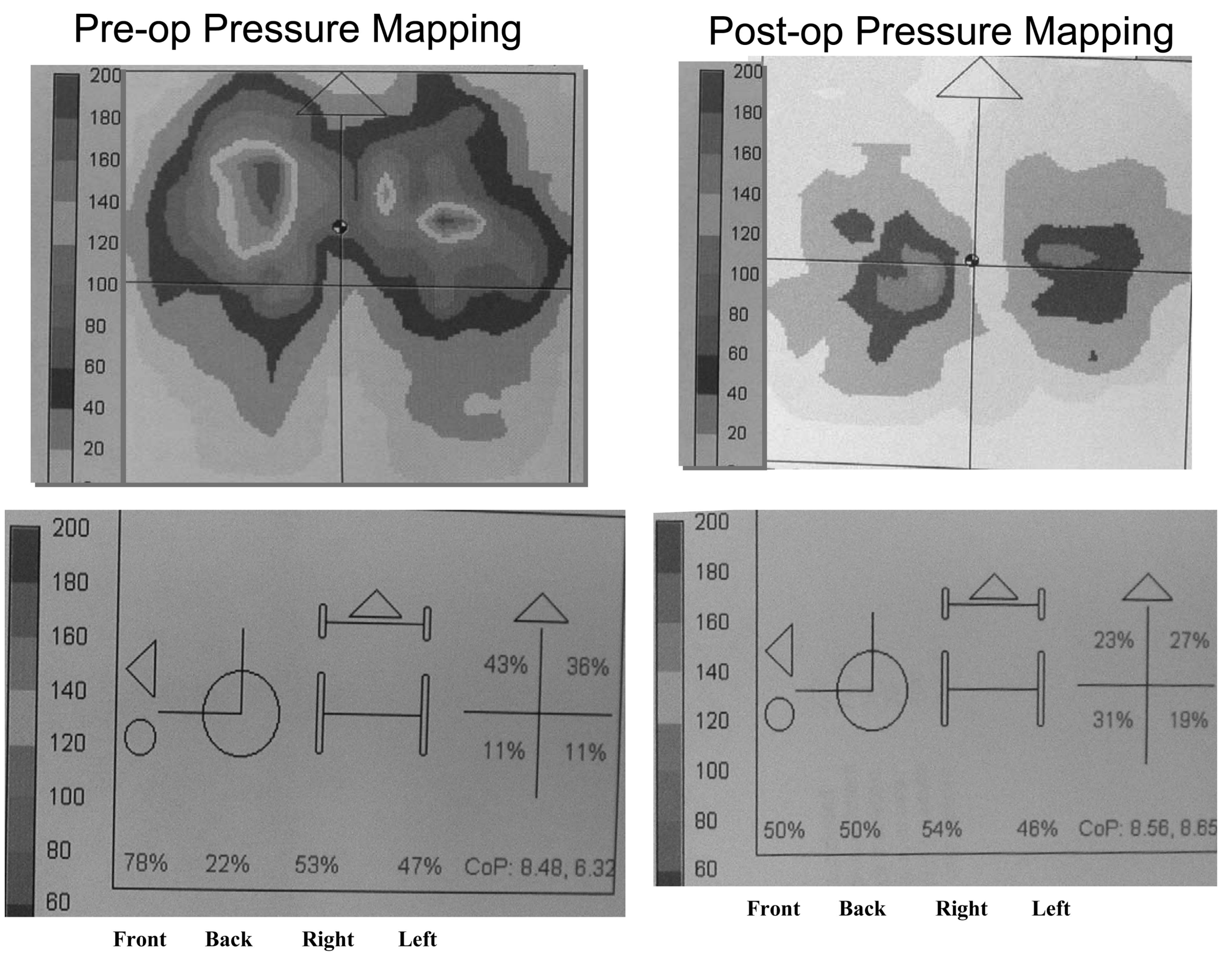


Figure 2. Example of improved pressure mapping distribution pre- to postoperative. Despite improvement patient developed post op skin ulceration.

pelvic fixation, 2 different techniques were used. Presacral Dunn-McCarthy rods were used when lumbosacral kyphosis needed correction,[25] while the M/W construct (iliac screws coupled with iliosacral screws acting as levers to distract or compress the hemi pelvis)[26] was used when pelvic obliquity needed correction. Bone grafts consisted of a combination of autograft (pelvis, rib, and tibia) and allograft.

Correction of the pelvic obliquity and verticalization were corrected by means of cantilevering both rods across the deformity, *i.e.*, from side to midline for pelvic obliquity, and from dorsal to front for kyphosis. Final correction of the pelvic obliquity was done by fine tuning the M/W fixation, while sagittal correction was dependant on rod contouring and *in situ* pending. Intraoperative 3-ft-long cassette radiographs were taken to assess coronal balance. Hip physiotherapy was delayed for 6 weeks after surgery, and self-transfer was permitted only at 12 weeks for patients who underwent fusion to the pelvis.

Results

Between January of 2003 to December of 2005, 19 consecutive wheelchair-dependant patients with a diagnosis of myelomeningocele and spino-pelvic deformities had corrective spinal surgery. All patients were observed in our outpatient multidisciplinary clinic, and also included detailed assessments by an occupational therapist and physical therapist.

Clinical Data

There were 9 girls and 10 boys. Their average age at operation was 13.6 years (7–19). At the time of surgery 10 patients were Riser 0, 3 were Risser 1, 2 were Risser 2, and 4 were Risser 5. There were 10 high lumbar dysraphism and 9 thoracic dysraphism. All 19 were wheelchair dependant although 3 remained able to walk with Canadian crutches. Of the 9 thoracic levels, 5 required hand assistance to maintain sitting balance, while only 3 of the lumbar levels required hand assistance for sitting. The distribution of spinal deformities was 6 scoliosis, 5 kyphosis, and 8 kyphoscoliosis.

Skin Ulceration

Of the 19 patients, 7 patients had preoperative skin ulcerations secondary to their spino-pelvic deformity. Two presented with decubitus ulcers, while the other 5 had skin ulcerations over their gibbous. At last follow-up, no patients had any ongoing skin ulcerations; however, 5

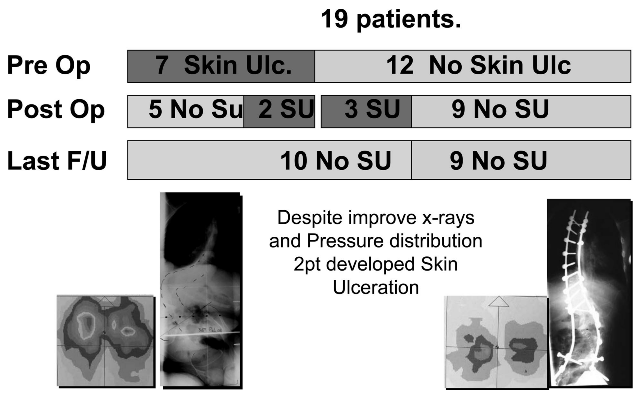


Figure 3. Overall skin ulceration.

patients had developed transient skin ulceration in the postoperative course.

Of the 7 patients with preoperative ulcerations, 5 had complete resolution of their skin ulcerations. The other 2 also had resolution of their skin ulceration however, they developed new transient skin ulcerations but at a different site.

Of the 12 that had no preoperative skin ulcerations, 3 developed *de novo* skin ulcerations (Figure 3).

Pressure Mapping

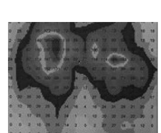
Overall, pressure mappings did not show statistically significant change from before surgery too after surgery up to the last follow-up visit. The variable coefficient remained at 88.5 (54.7–162.2) before surgery to 89.2 (53.1–123.6) at last follow-up. The maximal pressure and the average pressure also remained unchanged from before surgery to last follow up visit, 112.5 to 107.4 and 25.2 to 25.8, respectively. In respect to right and left, as well as, front and back pressure distribution, there was a trend toward improvement but not statistically significant. There was 18% improvement front and back while there was 33% improvement towards the center from right to left. Results did not change if patients were grouped based on myelomeningocele levels, deformity types, fixation types or sitting balance with or without hand assistance (Table 1).

Radiologic Results

All 19 patients had posterior spinal instrumentation and fusion. The proximal fixation reached T2 in 15 cases and T3 in 4 cases. Distal fixation was down to the pelvis in 16 cases, and 3 cases to L5. These 3 patients fused to L5 were wheelchair dependent but remained household "ambulators." Deformity correction for the group as a whole was as follows: scoliotic curves had an average preoperative value of 50° (3°–95°) and were corrected to 23.8° (0°–49°) with a *P* value of 0.002 (Table 2). The 5 kyphotic patients who had kyphectomies done had an average of 3 ½ vertebrae resected together with Dunn-McCarthy presacral pelvic fixation. Average preoperative kyphosis for these patients was 90° (60° to 180°). Immediate postoperative kyphosis was 18° and at last follow-up visit, kyphosis was 20° (3° to 45°) with a *P* value of 0.001. An extra 4 patients with kyphoscoliosis had Dunn-McCarthy for a total of 9 patients with this particular pelvic fixation. Seven patients had the M/W pelvic fixation to correct their pelvic obliquity. Their average preoperative pelvic obliquity was 20° (9°–35°). Their immediate postoperative and last follow up pelvic obliquity was 2° (0° to 5°) representing 89% correction with a *P* value of 0.001. In contrast to the patients who had kyphoscoliosis and pelvic obliquity which were treated with Dunn McCarthy fixation, their pelvic obliquity was corrected on an average of 56% from 9° (0–24) to 4° (0–13) with a *P* value of 0.08. The 3 patients that had no pelvic fixation had a mean preoperative pelvic obliquity of 12° which was corrected to 5° immediately after surgery and 9° at final follow up (Table 3). Coronal balance was improved in 14 of the 19 patients with a correction of 0.5 cm. The mean plumb line before surgery was 0.8 cm (range 0.3–12.8 cm) off the mid sacral line and it was reduced to 0.3 cm off the mid sacral line (range 0.3–4.6).

Correlations

Despite obtaining statistically significant corrections for scoliosis deformity, kyphosis deformity, pelvic obliquity, sacral slope and pelvic tilt, we did not record any significant changes in these patients's pressure mapping measurements. Using the Spearman's Rank Correlation, the only 2 correlations found among all possible pairing was the right to left coronal balance on radiograph correlated with pressure distribution right to left with a correlation coefficient of $R = 0.625$ and a *P* value 0.004. The second significant correlation found that the change in sacral slope correlated with the change of Variable coefficient

Table 1. Pressure Measurements 

	Preop	Postop	Δ	*P*
Variable coefficient	88.5 (54.7–162.2)	89.2 (53.1–123.6)	−0.7 (1%)	0.520
Average pressure	25.2 (9.6–58.8)	25.8 (12.6–59.2)	−0.6 (2%)	0.546
Maximum pressure	112.5 (31–200)	107.4 (52–200)	5.1 (5%)	0.981
Anterior/posterior	17 (−37 to 46)	14 (−33 to 29)	3 (18%)	0.965
Right/left	12 (−25 to 20)	8 (−26 to 23)	4 (33%)	0.825

Table 2. Coronal Measurements 

	Preop	Postop	Δ	*P*
Cobb angle (°)	50 (3–95)	23.8 (0–49)	25.7 (52%)	0.002
Pelvic obliquity (°) (M/W fixation)	20.0 (9–35)	2.3 (0–5)	17.7 (89%)	0.001
Coronal Balance (cm)	0.8 (0.3–12.8)	0.3 (0.3–4.6)	0.5 (62%)	0.747

Table 3. Sagittal Measurements 

	Preop	Postop	Δ	P
Thoracic kyphosis (°)	26.5 (−15 to 80)	19.7 (−32 to 47)	6.8 (26%)	0.157
Lumbar lordosis (°)	47.6 (−50 to 180)	32.8 (−20 to 75)	14.8 (31%)	0.295
Sacral slope (°) (Dunn McCarthy)	13.8 (38 58)	31.7 (7 57)	−17.9 (56%)	0.002
Pelvic tilt (°)	44.7 (7–100)	39.0 (9 75)	5.7 (13%)	0.395
Sagittal vertical axis (cm)	4.8 (2.0 16.5)	2.8 (7.5 14.0)	2.0 (42%)	0.205

with a correlation coefficient of $R = 0.545$ and a P value of 0.016. All other parameters did not correlate with pressure parameters (Figure 4).

While preoperative pressure mapping did correlate with the presence or absence of skin ulcerations, the post operative pressure mapping did not correlate with the presence or absence of skin ulcerations. Concretely, some of our patients whose pressure mappings were redistributed evenly after surgery still developed transient skin ulcerations while other patients who remained with abnormal pressure distribution R/L or F/B did not develop skin ulceration.

■ Discussion

Surgical management of neuromuscular scoliosis remains controversial primarily because of the relative high morbidity,[27] especially in myelomeningocele populations. Current concepts dictate that surgical management should be considered when there is curve progression or spinal imbalance and/or skin breakdown.[28] We have attempted to elicit the impact of modern spinal fixation on pressure mapping measurements of patient's undergoing spinal surgery as well as factors that may contribute to the development of skin ulcerations.

Our results demonstrate that surgery was able to significantly correct radiographic parameters (Cobb angle, pelvic obliquity, and sacral slope). Spinal fixation for neuromuscular scoliosis has been traditionally done from a posterior approach with sublaminar wire. The advent of pedicle screws has changed our ability to fix the spine of myelomeningocele patients. Anterior spinal instrumentation can also be done avoiding the deficient posterior elements. The type of pelvic fixation influences the amount of correction. The M-W construct was able to significantly correct and maintain pelvic obliquity while the Dunn-McCarthy construct was better to correct and maintain sacral slope. While significant changes in radiographic variables were observed after surgery, this was not the case with the various pressure mapping variables. Insignificant postoperative changes were observed in the average pressure, maximum pressure, and variable coefficient of pressure. What was observed was an improvement in the overall distribution from anterior/posterior and right/left which only approached statistical significance ($P = 0.053$). Interestingly, fusion to the pelvis or to L5 does not influence pressure distribution or the incidence of skin ulcerations. With the exception of ambulators, we recommend in wheelchair dependant pa-

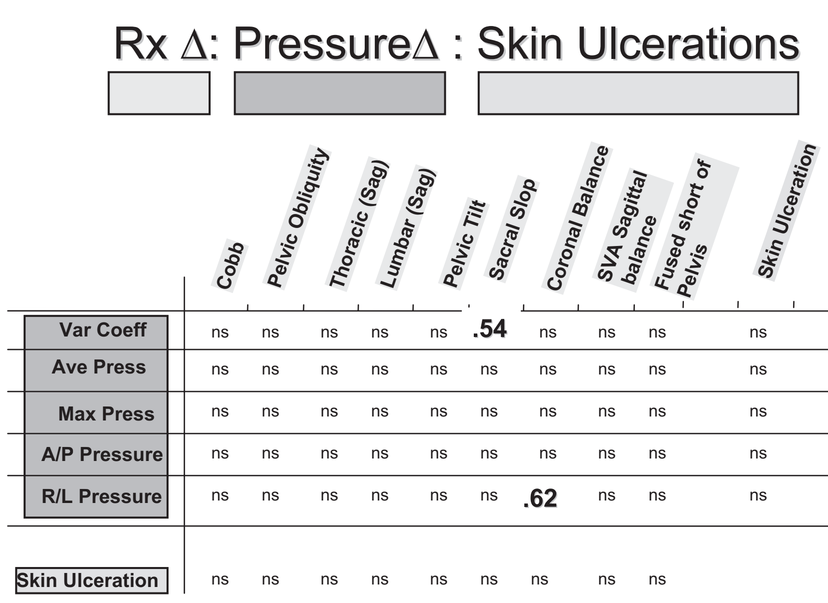


Figure 4. Surgically corrected factors that do influence sitting pressure. Note no specific influence on skin ulceration.

tient with myelomeningocele and pelvic obliquity to fuse then to the pelvis. Patients who ambulate with Canadian crutches tend to have a swing true gait. They often use their pelvis and some lumbar motion to thrust their legs forward. Our fear of fusing them to the pelvis is they may loose this thrust and hinder their ability to mobilize. Coronal balance as well as sacral slope did correlate with the variable coefficient. This confirms that coronal balance remains a priority when surgically correcting these deformities and that the sagittal orientation of the lumbo-sacral-pelvis junction does influence pressure distribution. Obtaining intra operative full spine radiographs not only in the AP view as we did but also in the LAT view may well further improve our ability to rebalance these patients.

Unfortunately our results did not provide us with the spatial orientation that this junction needs to be, to improve pressure distribution. Being in or out of coronal balance did influence, as previously stated, the distribution of pressure, however, this did not correlate with the development of decubitus ulcers. The changes in pressure distribution did not appear to be of any clinically significance as it did not correlate with presence or absence of skin ulcerations.

Despite having corrected their spinal imbalance as well as their pelvic obliquity, patients still had asymmetrical pressure distribution. Based on these results, one can draw different conclusions: (1) long spinal fusions for neuromuscular scoliosis negate the benefits of spinal realignment. The added long lever arms results in abnormal pressure distribution. The end result is that corrective spinal surgery does not alter pressure distribution for patients who are wheel chair dependant. Another conclusion which can be drawn is that, (2) the so-called corrections that we obtain remain ever so slightly out of balance and that X degree of residual pelvic obliquity or the residual coronal or sagittal imbalance is enough to maintain the abnormal pressure distribution. It is also possible that there is a, (3) residual deformity that our surgery does not address such as pelvic rotation along the long axis of the spine, which results in abnormal distribution across the ischium.

Drummond *et al* defined several risk factors for the development of pressure sores which included maldistribution of pressure caused by spino-pelvic deformity.[18] Our results also concurred that patients who are out of balance in the coronal plan have asymmetrical pressure mapping, however, it does not necessarily result in skin ulcerations. Factors influencing skin breakdown in this patient population appears multifactorial. Insensate skin, lack of interposed myofascial plains between bony prominences and skin, poor skin circulation and constant pressure are all factors which contribute to the development of skin ulceration.

As no patient at the last follow-up had any active pressure sores, this indicates that there is an adaptation period that the skin undergoes after surgery to the new pressure distribution. If the skin is placed under constraints too quickly, and that even though the pressure distribution has been equalized, the skin may still ulcerate as it has not had the time to adapt. It is crucial that once spinal realignment and balance has been achieved, that vigilance remains and that a scheduled sitting duration is implemented to allow the skin that is now bearing the brunt of the pressure time to adapt to its new role.

Corrective spinal surgery in patients with myelomeningocele remains a significant challenge on many levels. We currently have a good understanding of managing spinal alignment which surgery can significantly improve. However, spinal balance and its direct impact on sitting pressure distribution require further studies. We have demonstrated that despite significant corrections in radiographic parameters, we obtained only small changes in patient pressure distribution. Treatment of radiologic parameters alone is insufficient in managing these complex patients if one hopes to minimize their incidence of pressure sores.

■ Key Points

- Despite significant surgical correction in radiographic parameters, these resulted in small changes in pressure distributions.
- Pressure mapping may not be a useful tool in predicting outcome of spinal surgery.
- Skin ulceration is probably a result of multiple factors and that spinal deformities may not be the critical factor.
- Factors which were proven to influence pressure distribution are the sagittal pelvic orientation and also achieving coronal spine balance.

References

1. Herring JA. *Tachdjian's Pediatric Orthopaedics*. 4th ed. Saunders Elsevier; 2008.
2. Guille JT, Sarwark JF, Sherk HH, et al. Congenital and developmental deformities of the spine in children with myelomeningocele. *J Am Acad Ortho Surg* 2006;14:294–302.
3. Trivedi J, Thomson JD, Slakey JB, et al. Clinical and radiographic predictors of scoliosis in patients with myelomeningocele. *J Bone Joint Surg Am* 2002; 84:1389–94.
4. Piggott H. Natural history of scoliosis in myelodysplasia. *J Bone Joint Surg Br* 1980;62-B:54–8.
5. Eysel P, Hopf C, Schwarz M, et al. Development of scoliosis in myelomeningocele. Differences in the history caused by idiopathic pattern. *Neurosurg Rev* 1993;16:301–6.
6. Iborra J, PageÂE, Cuxart A. Neurological abnormalities, major orthopaedic deformities and ambulation analysis in a myelomeningocele population in Catalonia (Spain). *Spinal Cord* 1999;37:351–7.
7. Müller EB, Nordwall A. Prevalence of scoliosis in children with myelomeningocele in western Sweden. *Spine* 1992;17:1097–102.
8. Yann Glard, Franck Launay, Elke Viehweger, et al. Neurological classification in myelomeningocele as a spine deformity predictor. *J Pediatr Orthop B* 2007;16:287–92.
9. Müller BM, Nordwall A, Odén A. Progression of scoliosis in children with myelomeningocele. *Spine* 1994;19:147–50.
10. Kinsman SL, Doehring MC. The cost of preventable conditions in adults with spina bifida. *Eur J Pediatr Surg* 1996;6(suppl 1):17–20.
11. Harris MB, Banta JV. Cost of skin care in the myelomeningocele population. *J Pediatr Orthop* 1990;10:335–61.
12. Kahanovitz N, Duncan JW. The role of scoliosis and pelvic obliquity on functional disability in myelomeningocele. *Spine* 1981;5:494–7.

13. Mazur J, Menelaus MB, Dickens DR, et al. Efficacy of surgical management for scoliosis in myelomeningocele: correction of deformity and alteration of functional status. *J Pediatr Orthop* 1986;5:568–75.
14. Maloney WJ, Rinsky LA, Gamble JG. Simultaneous correction of pelvic obliquity, frontal plane and sagittal plane deformities in neuromuscular scoliosis using a unit rod with segmental sublaminar wires: a preliminary report. *J Pediatr Orthop* 1990;10:742–9.
15. McMaster MJ. Anterior and posterior instrumentation and fusion of thoracolumbar scoliosis due to myelomeningocele. *J Bone Joint Surg Br* 1987;69: 20–5.
16. Parsch D, Geiger F, Brocai DR, et al. Surgical management of paralytic scoliosis in myelomeningocele. *J Pediatr Orthop B* 2001;10:10–7.
17. Wai EK, Young NL, Feldman BM, et al. The relationship between function, self-perception, and spinal deformity. Implications for treatment of scoliosis in children with spina bifida. *J Pediatr Orthop* 2005;25:64–9.
18. Drummond D, Breed AL, Narechania R. Relationship of spine deformity and pelvic obliquity on sitting pressure distributions and decubitus ulceration. *J Pediatr Orthop* 1985;5:396–402.
19. Ward TW, Wenger RW, Roach JW, et al. Surgical correction of myelomeningocele scoliosis: a critical appraisal of various spinal instrumentation systems. *J Pediatr Orthop* 1989;9:262–8.
20. Yazici M, Asher MA, Hardacker JW, et al. The safety and efficacy of Isola-Galveston instrumentation. Instrumentation and arthrodesis in the treatment of neuromuscular spinal deformities. *J Bone Joint Surg Am* 2000;82-A:524–43.
21. Modi HN, Suh S, Song H, et al. Treatment of neuromuscular scoliosis with posterior-only pedicle screw fixation. *J Orthop Surg Res*, 2008;3:1–8.
22. Rodgers WB, Williams MS, Schwend RM, et al. Spinal deformity in myelodysplasia. Correction with posterior pedicle screw instrumentation. *Spine* 1997;22:2435–43.
23. Gupta MC, Wijesekera S, Sossan A, et al. Reliability of radiographic parameters in neuromuscular scoliosis. *Spine* 2007;32:691–5.
24. Weinstein SL, Zavala DC, Ponseti IV, et al. Idiopathic scoliosis: long-term follow-up and prognosis in untreated patients. *J Bone Joint Surg Am* 63: 702–12.
25. McCarthy RE, Bruffett WL, McCullough FL. S rod fixation to the sacrum in patients with neuromuscular spinal deformities. *Clin Orthop Relat Res* 364: 26–31.
26. Arlet V, Marchesi D, Papin P, et al. The "MW" sacropelvic construct: an enhanced fixation of the lumbosacral junction in neuromuscular pelvic obliquity. *Eur Spine J* 1999;8:229–31.
27. Askin G, Hallett R, Hare N, et al. The outcome of scoliosis surgery in the severely physically handicapped child: an objective and subjective assessment. *Spine* 22:44–50.
28. Ouellet JA, Arlet V. Neuromuscular scoliosis. In: Boos N, Aebi M, eds. *Spinal Disorders: Fundamentals of Diagnosis and Treatment*. Berlin, Heidelberg: Springer-Verlag; 2008.