Systematic Review of the Impact of Pelvic Obliquity in Patients with Neuromuscular Scoliosis

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Introduction

Scoliosis is common in patients with neuromuscular diseases—especially those with impaired trunk strength and/or control who are unable to ambulate. This scoliosis may impact seating, ease of care, pulmonary function, and quality of life. The typical long, sweeping thoracolumbar or lumbar curve patterns of these patients are often associated with pelvic obliquity (PO, tilt of the pelvis in the coronal plane).[1] While PO may be driven by scoliosis (a supra-pelvic cause), infra-pelvic causes of PO such as hip abduction/adduction contractures may also contribute.[2-7] As a result, the relationship between supra- and infra-pelvic deformities and PO is complex and unpredictable.[2,5,6,8-11]

PO in the patient with neuromuscular disease may interfere with seating balance and tolerance and may even lead to pressure sores.[7,12,13] However, it remains unclear what magnitude of PO can be reliably tolerated with external seating modifications alone.[14,15] Similarly, when surgical correction of neuromuscular scoliosis (NMS) is indicated, it is not known what degree of residual pelvic obliquity is acceptable and can be accommodated easily with seating modifications for non-ambulatory patients.

This concept is important because correction of significant supra-pelvic-driven PO in the setting of neuromuscular scoliosis in non-ambulatory patients is generally thought to require extending the spinal fusion construct to the pelvis, which comes with increased risk of complications such as infection and implant failure.[16] With this in mind, ending the spinal fusion construct in the lower lumbar spine (rather than the pelvis) has been considered in selected cases of NMS in non-ambulatory patients, even though it is expected to leave a larger residual PO. Thus, the goal of this systematic review is to compile and assess the available literature detailing the impact of PO on seating, function, ease of care, risk of ulceration, and/or quality of life in patients with NMS to better understand what degree of PO may be acceptable.

Methods

Data Sources

We performed a literature search for articles detailing NMS and PO in May of 2018. Studies from PubMed, Embase, and CINAHL were queried. Our search structure is detailed in Figure 1. We searched for the terms pelvic obliquity and scoliosis in combination with each of the following words or phrases: neuromuscular, spinal fusion, cerebral palsy, spina bifida, myelodysplasia, muscular dystrophy, spinal muscular atrophy, seating, and sitting balance. This search strategy was modified for each of the databases used. No specific date restriction was used, though articles were only searchable for the years covered by the databases (PubMed 1966 – present, Embase 1947 – present, CINAHL 1937 – present).

Study Selection

Studies were subsequently screened to identify those detailing untreated NMS and PO and their relationship to any one of seating, skin breakdown or pressure sores, patient/caregiver-reported pain, quality of life, or ease of care. After removal of duplicates, the initial search returned a total of 2,021 articles or abstracts (Figure 1). Titles were screened independently by two authors (TL, CD) and any study receiving 1 or 2 votes was advanced for abstract review. Only peer-reviewed studies published in English were included, while reviews and chapters were excluded. 1,442 studies were excluded based on title irrelevance. Abstract review was conducted in a similar fashion, after which another 318 studies were excluded. This left 293 studies for full-text review. After full text review (TL, CD), the final set of studies was examined, and data was compiled. Additionally, the references of each included study were

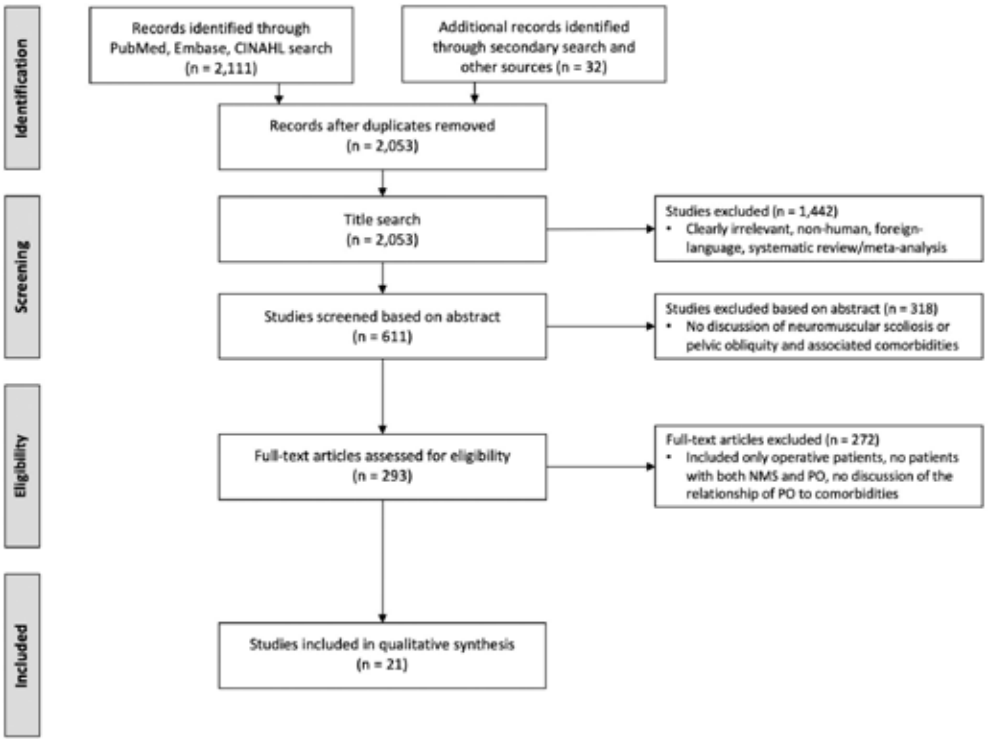

Figure 1. PRISMA diagram.

reviewed to identify articles that did not appear in the original search, yielding an additional 32 relevant studies. These were independently reviewed and included in the final data synthesis.

During review, only studies of the natural history (non-operative scoliosis management) of patients with neuromuscular disorders were advanced for consideration. These studies included patients both NMS and PO, some with a mixture of operative and non-operatively managed scoliosis patients that detailed PO and its relationship to the aforementioned comorbidities. Study level of evidence (LoE) was determined and consensus reached by three authors (JB, KB, DS) based on the criteria established by the Oxford Centre for Evidence-Based Medicine.[17] Conclusions were then drawn and grades of recommendation assigned based on established criteria again by three authors (JB, KB, DS), with disagreements resolved through discussion.[18] Using this system, a grade A = good evidence (level-I studies with consistent findings) for or against recommending intervention, grade B = fair evidence (level-II or III studies with consistent findings) for or against recommending intervention, grade C = conflicting or poor-quality evidence (Level-IV or V studies) not allowing a recommendation for or against intervention, and grade I = there is insufficient evidence to make a recommendation.

Data Extraction

Twenty-one studies were included in the final review (Table 1). Information was catalogued through manual review and kept in a spreadsheet (Excel, Microsoft, Redmond, WA). Data was extracted primarily by three authors (CD, JB, WA). Extracted data included study design, population demographics, quality of life and other associated findings, scoliosis or PO progression history, and any author conclusions.

Results

Pelvic obliquity has a deleterious effect on seating balance (grade B)

The most commonly cited problem arising from PO is "sitting imbalance", which has not been defined. Fourteen studies discussed sitting imbalance and its relationship to PO (Table 2) usinþain upright with push, or unstable = cannot sit without support) was associated with deterioration in spinopelvic angle and PO (PO of 0.7˚, 4.3˚, and 7.3˚, respectively for each group).27 Several other studies–4 level II, 2 level III, and 1 level IV–similarly noted that worsened sitting function (typically assessed using a subjective binary scale of balanced vs unbalanced) and functional status are associated with higher magnitudes of PO and resulting coronal imbalance.[4,19-21,23,25,28] One level IV article specifically noted mean PO 41˚ vs 22˚ for unbalanced and balanced sitters, respectively.[19] Another level 2 study showed higher pelvic obliquity in poor sitters versus good sitters.[20] In contrast, patients determined to be good or stable sitters more often have a level pelvis compared to those who require propping or who are bedridden (1 level III and 1 level IV paper).[5,9] It remains unclear whether PO drives sitting imbalance, as associated hip flexion contractures have also been shown to increase the odds of concomitant PO, trunk asymmetry, scoliosis,

Table 1. Study Characteristics

Author	Patients	LOE	Diagnosis	Operative *	Scoliosis†	Pelvic Obliquity†	Quality of Life	Function
Ágústsson[26]	714	3	CP	NR	286 (40%)	672 (94%)	-	PPAS
Bartnicki[20]	19	2	Myelomeningocele	0 (0%)	19 (100%)	17 (80%)	QOL-SBQ, HSDI-C, HSPPA, SBSQ, ASKp	Hoffer, ASKp
Drummond[12]	16	4	Neuromuscular Scoliosis	9 (56%)	12 (75%)	9 (90%) patients with high ischial loading	-	-
Kahanovitz[19]	39	4	Myelomeningocele	23 (59%)	39 (100%)	NR	-	Hoffer
Kalen[28]	56	3	CP	0 (0%)	14 (25%) curves ³45˚, 42 (75%) curves <45˚	8 (57%) of patients with curves ³45˚	-	Other
Khoshbin[24]	11	3	Spina Bifida	0 (0%)	11 (100%)	NR (mean 12.9˚)	SBSQ, SF-36	Hoffer, SBS
Knapp[10]	29	4	CP (Hip Dislocation)	NR	21 (72%)	12 (41%)	-	
Majd[13]	56	4	CP	0 (0%)	51 (91%)	NR (mean >10˚)	-	Hoffer
Moreau[14]	30	4	CP	NR	14 (47%)	14 (47%)	-	Hoffer
Murans[31]	14	3	Neuromuscular Scoliosis	0 (0%)	14 (100%)	10 (71%)	-	Other
Nielsen[32]	13	3	Neuromuscular Scoliosis (54%)	7 (54%)	13 (100%)	11 (85%)	-	-
Patel[30]	32	4	Myelodysplasia	7 (22%)	32 (100%)	NR (mean 15˚)	-	-
Pritchett[9]	50	3	CP (Unstable Hips)	NR	43 (86%)	30 (60%)	-	Other
Pritchett[5]	80	4	CP (Unstable Hips)	NR	68 (85%)	45 (56%)	-	Other
Sewell[29]	15	3	CP	0 (0%)	15 (100%)	NR (mean 12˚)	CP-CHILD	CP-CHILD
Sewell[34]	36	3	CP	0 (0%)	36 (100%)	NR (mean 14˚)	ASKp	ASKp
Shoham[33]	15	4	Neuromuscular Scoliosis	0 (0%)	15 (100%)	15 (100%)	-	-
Sibinski[21]	19	2	Myelomeningocele	0 (0%)	19 (100%)	17 (89%)	QOL-SBQ, HSDI-C, HSPPA, SBSQ, ASKp	Hoffer, ASKp
Smith[27]	39	3	Myelodysplasia	6 (15%)	23 (60%)	15 (39%)	-	Other
Suk[25]	26	2	Duchenne Muscular Dystrophy	0 (0%)	26 (100%)	NR (mean 29˚)	MDSQ	Modified Rancho Scale
Wai[23]	80	2	Myelodysplasia	24 (30%)	80 (100%)	NR (mean 9˚)	HSDI-C, HSPPA, SBSQ, ASKp	Hoffer, ASKp, SBS, Other

*Number (percentage) of patients who had undergone attempted spinal fusion at time of evaluation. Studies that did not state the specific number of operatively managed patients (NR = not reported) primarily described patients

uneven weight distribution, and windswept hip distortion, the combination of which leads to poor seating posture (level III).[26] From the 14 studies discussing the relationship of PO to sitting balance (4 level II, 8 level III, 2 level IV), the overall consensus is that PO likely contributes to but is not an isolated cause of sitting imbalance, earning a grade of B for relatively consistent findings with a fair level of evidence.

A threshold of pelvic obliquity exists past which sitting imbalance is likely (grade I)

One level IV article by Kahanovitz et al suggested that maintenance of ambulation and prevention of spine imbalance appeared to correlate with a major curve angle below 40˚ and PO less than 25˚.[19] While PO may impact sitting balance, a threshold or "tipping point" after which this causes symptoms such as seating intolerance remains unclear and may vary somewhat by patient. As only one level IV study specifically addressed the threshold at which PO may become problematic for sitting imbalance, there is grade I (insufficient) evidence to answer this question.

Pelvic Obliquity is associated with difficulty with perineal care (grade I)

Five studies discussed positioning or perineal care, though none described PO thresholds above which positioning and/or perineal care becomes particularly difficult (Table 3). Difficulties in perineal care were noted in 3-38% (2 level III and 2 level IV studies) of patients, but in some cases this was attributed to concomitant hip contractures or subluxation/dislocation (concomitant infra-pelvic causes of PO).[4,5,9,10] One level III study found that

Table 2. Studies Discussing Sitting Imbalance

Author	Sitting Imbalance
Ágústsson[26]	Asymmetric limited hip flexion <90° increased odds of PO, trunk asymmetry (i.e. poor sitting posture) – both items from the PPAS – scoliosis, and windswept hip distortion.
Bartnicki[20]	Poor sitters as evaluated by the article authors on a 3-point sitting stability scale had significantly greater PO (15° vs 9°) than good sitters, concluding that improved sitting stability correlated with decreased PO. Additionally, the odds of community ambulatory status was 2.5 times higher for stable sitters.
Kahanovitz[19]	Of 11 unbalanced sitters, 10 had scoliosis >35° and PO >25° whereas all ambulators (balanced sitters per the authors' definition) had PO <25°. Nine non-ambulatory but balanced sitters had mean PO of 22° vs 41° for unbalanced sitters.
Kalen[28]	Patients with higher major curve severity (>45°) and PO were more frequently lower functioning (e.g. less ambulatory) and required wheelchair modification to help with sitting function (81% vs 46%).
Khoshbin[24]	Of 9 non-operatively treated patients with available follow-up assessment, 3 (33%) required arms for sitting support on the SBS with a mean PO of 12.9°.
Moreau[4]	The authors concluded that a combination of PO and scoliosis led to loss of sitting balance in 9 of 14 (64%) of patients with either hip subluxation or hip dislocation.
Pritchett[9]	All self-propped sitters had a level pelvis (compared to propped or bedridden patients).
Pritchett[5]	All self-propped sitters had a level pelvis (compared to propped or bedridden patients).
Sewell[29]	Decreased CP-CHILD scores over 2 years were attributed to worse sitting balance and pain with a noted 4° increase in PO, though these results were not specifically correlated to final PO.
Sewell[34]	Decreased ASKp scores over 2 years were attributed to worse sitting balance and pain with an observed 4° increase in PO, though these results were not specifically correlated to final PO.
Sibinski[21]	While eight patients (42%) had poor sitting, there was no relationship between PO and any QoL metric evaluated. However, there was an observed correlation between PO and major curve magnitude as well as between sitting stability and QoL on the SBSQ. The authors concluded that severe scoliosis affects QoL and is associated with higher magnitude PO.
Smith[27]	Sitting stability was most closely associated with spinopelvic angle as well as intra-pelvic PO (mean values of 0.7°, 4.3°, and 7.3° for stable, poor, unstable sitters, respectively).
Suk[25]	MDSQ sitting scores for questions relevant to sitting – scores of 0 indicating the inability to perform a task and 4 indicating independence – were all below a mean 1.5 in a population with mean PO 29° at follow-up. However, the specific correlation between sitting scores and PO was not explored.
Wai[23]	Coronal imbalance, not major curve magnitude or PO, was the only factor found to correlate with the sitting balance, though the inclusion of operative and non-operatively managed patients in the regressions is unclear. Further the authors suggest that specific attention should be paid to correction of coronal balance through curve correction and leveling of PO.

Table 3. Studies Discussing Sitting Positioning, Perineal Care, and Pain

Author	Positioning, Perineal Care, and Pain
Knapp[10]	Eleven of 29 patients (38%) had difficulty with perineal care, which was more frequently attributed to severe adduction contractures in this cohort of patients with hip subluxation/dislocation.
Moreau[4]	In a subset of 30 patients with hip subluxation or dislocation - 14 of whom had PO and scoliosis - 11 were reported to have difficulty with perineal care.
Pritchett[9]	Two patients had perineal care difficulty, and 21 had minor/moderate pain attributed primarily to hip subluxation.
Pritchett[5]	Two patients had perineal care difficulty, and 30 had minor/moderate pain attributed primarily to hip subluxation.
Sewell[29]	Twelve patients (83%) initially reported no spinal-related pain, while at 2-year follow-up 66% reported mild or moderate spinal-related pain. However, this not specifically correlated with final PO, and there was no noted change in positioning or transferring despite the increase in PO.

caregivers did not observe any change in the positioning, transferring, or mobility of patients on the Caregiver Priorities & Child Health Index of Life with Disabilities questionnaire (CP-CHILD) despite an increase in mean PO from 8° to 12° over 2 years.[29] With only five lower-quality studies on this topic, it is difficult to assess the contribution of PO to these outcomes, and therefore we assign a grade of I for insufficient evidence that PO is associated with perineal care and positioning difficulties.

Pelvic Obliquity is associated with decubitus ulcers and skin breakdown (grade C)

The association between PO and skin breakdown is likely multifactorial and has been discussed in thirteen studies (Table 4). The lifetime incidence of decubitus ulcers in the neuromuscular population (e.g. CP, myelodysplasia, muscular dystrophy) ranged from 5-69% across 1 level II, 4 level III, and 5 level IV studies,[4,5,9,10,12,13,20,24,28,30] with the majority of ulcers in these patients tending to be sacral[13,28] or trochanteric.[5,9] A level IV study by Drummond et al suggested that risks of ulceration include >55% posterior weight distribution, >30% weight distributed over one ischium, >11% weight over sacro-coccygeal region, and non-ambulation; the risk was highest when 3 or more criteria were met.[12] Two level III studies consistently found greater seat load asymmetry with higher magnitude PO, though one of these showed a non-significant difference in PO compared to controls.[31,32] A level II study by Shoham

Table 4. Studies Discussing Decubitus Ulcers

Author	Decubitus Ulcers
Bartnicki[20]	25% of poor sitters had a history of decubitus ulcer (defined as major or minor) vs 18% of good sitters (non-significant results).
Drummond[12]	A total 10 of 16 paraplegic patients evaluated had history of ulcer, 9 of whom were noted to have asymmetric seating loads, which the authors concluded was associated with unbalanced scoliosis and PO.
Kalen[28]	Decubiti were noted in 22% of patients with major curves >45˚ (57% of whom had PO) vs 15% of patients with curves <45˚ (0% with PO). Authors concluded no correlation between PO or scoliosis and decubiti.
Khoshbin[24]	Only 1 patient (9%) had a decubitus ulcer at baseline assessment.
Knapp[10]	A total of 9 patients (31%) had a history of decubitus ulcers.
Majd[13]	Three patients evaluated with history of decubitus ulcer had mean PO of 45˚ and major curve of 106˚ in comparison to mean PO and major curve of 12˚ and 57˚ in non-ulcer patients, respectively. The authors concluded that a relationship exists between larger deformity (PO and major curve) and the risk of ulcer development.
Moreau[4]	Nine of 30 patients (30%) with hip subluxation or dislocation decubitus ulcers, all of whom were bedridden. The authors concluded that the ability to sit is greatly reduces the risk of decubiti, which they stated is impacted by PO and scoliosis.
Murans[31]	NMS patients have greater seat load asymmetry vs controls (30% vs 7%). However, PO in the NMS cohort (mean 13.5˚) was not significantly greater than controls.
Nielsen[32]	Evaluation of seat load characteristics in 13 children (mean PO 19.1˚) able to independently sit showed higher peak pressure (331.3 g/cm^3 vs 219.6 g/cm^3) and percent of body weight (61.6% vs 51.2%) on the side carrying the larger load vs controls. The top 25% of pressure was distributed over smaller area (10.2 cm^2 vs 27.0 cm^2) in NMS.
Patel[30]	Twenty-two of 32 patients (69%) had a history of at least one ulcer. The authors noted greater PO correlated with higher average and peak seated pressures as well as larger proportion of areas with high pressure. However, the magnitude of curve, PO, and seated pressures were similar in patients without history of ulcer.
Pritchett[9]	Twelve patients (24%) had a history of ulcer, which were noted to mostly be trochanteric or sacral (60% had PO).
Pritchett[5]	Nineteen patients (21%) had a history of ulcer (13 trochanteric, 6 sacral) in a population where 56% had PO.
Shoham[33]	There was no observed correlation between PO and seating pressure at baseline, but use of a TLSO improved seating pressure in patients with PO elevation contralateral to the convexity of the major curve.

et al also showed that TLSO bracing significantly improved seating pressure in patients with NMS and PO, and therefore recommended bracing treatment in this subset of NMS patients to reduce localized interface pressure and prevent decubitus ulcers.[33] The most commonly cited positive association is a level IV study of non-ambulatory adults with CP by Majd et al., which found that 3 patients with decubitus ulcers had significantly larger PO (45˚ vs 12˚) and major curve angles (106˚ vs 57˚) compared to the remaining 53 individuals.[13] In contrast, several other studies (1 each of level II, III, and IV) have found no difference in PO between patients with and without a history of ulcer development.[20,28,30] Despite an intuitively increased risk of decubitus ulcers relating to significant PO given increased seating pressures over small areas seen in these patients, there is conflicting, grade C evidence that higher magnitude PO contributes to the development of decubitus ulcers.

Untreated pelvic obliquity in NMS is associated with decreased HRQOL (grade C)

Regardless of the contributions of PO to sitting imbalance, ulcer development, or difficulty positioning patients, it is perhaps most important to understand its impact on quality of life (QoL). Seven studies reported or discussed PO in NMS patients with recorded QoL metrics, including: CP-CHILD29, Quality of Life in Spina Bifida Questionnaire (QoL-SBQ),[20,21] Spina Bifida Spine Questionnaire (SBSQ),[20,21,23,24] Muscular Dystrophy Spine Questionnaire (MDSQ)25, Short Form Health Survey (SF-36)24, Activities Scale for Kids (ASKp),[20,21,23,34] Health Self-Determinism Index for Children (HSDI-C),[20,21,23] and Harter's Self-Perception Profile for Adolescents (HSPPA).[20,21,23] While non-operatively managed patients tend to experience overall decreases in QoL as their scoliotic and pelvic deformities worsen—often attributed to impairments in sitting balance and pain[21,24,25]—3 studies (1 level II, 2 level III) did not find a correlation between QoL and PO.[21,29,34] Sibinski et al (level II) specifically demonstrated a significant correlation between sitting balance and SBSQ score, but failed to identify a correlation for PO with any index of HRQoL.[21] Suk et al. (level II) showed lower subsection scores related to sitting balance on the MDSQ for patients with high mean major curve angles of 106˚ and PO of 29˚, but did not report on the relationship of QoL and PO specifically.[25] A single level II paper identified better sitting stability (good vs poor sitters) and increased quality of life (QoL-SBQ) in patients with decreased PO (9˚ vs 15˚; not affected by major curve angle).20 There is conflicting evidence (grade C) that PO—which is often used as an indication for surgical intervention—is associated with decreased QOL in NMS.

Untreated pelvic obliquity in NMS is associated with increased pain (grade I)

There is also some evidence of an association between PO and pain, particularly as it relates to sitting imbalance. Patients with cerebral palsy (CP) showed significant

increases in pain over a 2-year period in one level III study with a concomitant increase in PO in one study from 8° to 12°, attributed primarily to worsened sitting balance.[29] While not explicitly comparing PO and pain, three other studies (1 level III, 1 level IV) reported rates of mild to major pain in patients with NMS and PO ranging from 33-60%.[5,9,10] Therefore, there is grade I (insufficient) evidence that PO is associated with higher pain.

Discussion

Pelvic obliquity—tilting of the pelvis in the coronal plane—may be driven by supra-pelvic (thoracolumbar/lumbar scoliosis) and/or infra-pelvic (contracture or subluxation/dislocation of hips) deformities. The finding is most commonly observed in non-ambulatory patients with neuromuscular disease, trunk weakness, and abnormalities in muscle tone and control that impair sitting balance. Many of these patients are unable to maintain an upright posture even in the absence of deformities above or below the pelvis. Previous studies have failed to define any consistent or predictable relationships between PO and supra- and/or infra-pelvic deformities. It is generally assumed that "significant" PO may be associated with pain, risk of skin breakdown, and impaired seating. While it has also been assumed that the goal of spine surgery in neuromuscular disease patients is a straight spine over a level pelvis, it remains unclear just what degree of pelvic obliquity can be tolerated given innovations in the design of current seating systems. To better understand this, we undertook this study of PO and its impact in the natural history of patients with NMS and PO. Our goal was to evaluate the relationship between PO and seating, attempting to determine the degree of obliquity that leads to symptoms, impairments, or alterations in quality of life.

The results of this review highlight the paucity of literature in this subject area. The first challenge is simply quantifying PO, and a variety of measurements have been described (Table 5). Further, only a subset of studies that did report PO (8/21) even stated which method was utilized. And the studies that did report what method was used reported a variety of methods. One can assess the degree of tilt relative to the horizontal plane, or for example the relationship of the spine to the pelvis which also assesses coronal balance (e.g. Maloney method). Schrader et al concluded that the Maloney method was most reliable with ICC ranges for inter- and intra-rater reliability of 0.964-0.965 and 0.845-0.962, respectively.[35] The Maloney method also has the advantage of relating the pelvis to the upper thoracic spine and overall spinal balance. Many studies use the Osebold or O'Brien methods which do not relate PO to the upper thoracic spine or overall spinal balance.[36] As such, we recommend future study standardize the method of PO measurement, preferably with Maloney as it has technical advantages as well as being shown to be the method with the most inter-rater reliability.

We also recognize that there are multiple variables that impact symptoms, function, and ease of care in non-ambulatory patients with neuromuscular conditions, such as weakness, challenges with controlling movement and balance, fixed supra- and infra-pelvic deformities, nutritional status and skin condition, and others, and our results suggest that it is impossible to disaggregate the impact of pelvic obliquity as an isolated variable. Many patients simply have weakness and poor trunk control and therefore have sitting imbalance and/or intolerance. This makes assessing the impact of PO very difficult. So while there seems to be an association between PO, sitting imbalance, and the development of skin breakdown, we were unable to identify a PO threshold that allows for reliable symptom/complication risk stratification. A single study found that maintenance of ambulation and prevention of spine imbalance was associated with a major curve angle below 40° and PO less than 25°.[19] Rates of decubitus ulcers varied significantly across neuromuscular

Table 5. Common Methods of Measuring Pelvic Obliquity[36]

Method	Description of Measurement Technique	Number
Not discussed	-	13
Osebold	One line is drawn between the most proximal points on the iliac crests and a second line intersecting the first is drawn parallel to the lower edge of the radiograph. The angle of intersection between these lines is the PO angle.	6
O'Brien	The pelvic coronal reference line is drawn using one of three methods depending on radiograph quality (in order: across tips of sacral alae, the iliac crests, greater sciatic notch). The angle formed by the intersection of this line and a line parallel to the lower edge of the radiograph is the PO.	1
Other	Intra-pelvic obliquity, defined as the angle formed between lines drawn across the iliac crests and across the base of the ischial tuberosities	1
Maloney	One line is drawn across the superior aspect of the iliac crests and a second line is drawn from the center of T1 to the center of S1. The angle of PO is then determined by measuring the angle between the second line and a line perpendicular to the first line.	0
Allen and Ferguson	A line is drawn across the iliac crests as in the Osebold method, with a corresponding perpendicular line drawn. A third line is then drawn intersecting the spinous processes of both the L4 and L5 vertebrae. The angle formed by the intersection of this third line with the perpendicular line is the PO.	0
Lindseth	A line is drawn perpendicular to the superior aspect of the top vertebra of a lumbosacral curve, with a second line drawn perpendicular to a line through the superior acetabular or inferior ischial tuberosity margins. The angle created by the intersection of these lines is the PO.	0

patients with differing degrees of PO. Patel et al. noted that ulcer location is often not described and seating modifications are not documented.[3]0

PO has not been specifically linked with any functional measure given that the few available measures of QoL and seating in the neuromuscular population do not specifically assess the contribution of PO. Several studies have noted that sitting balance correlates with the desires of caregivers and patient positioning rather than the actual deformity.[5,10] The limited existing metrics on QoL are unable to isolate the impact of a tilted pelvis, except those that specifically look at sitting (such as the Posture and Postural Ability scale or the Sitting Balance Scale). Motor strength and control and/or other variables are likely important, and wheelchair modifications may lead to adequate compensation for deformity.[23] From a measurement standpoint, it is unclear if any of these measures can detect the necessary change to identify improvements following surgery. Although this study focused on the experience in non-surgical treatment of patients with NMS, at least one study showed that parents viewed spinal fusion as one of the most helpful procedures for their child, edged out only by gastrostomy tube placement.[37]

Several limitations to this review should be noted. First, many of the studies were older studies, with all the methodologic flaws attendant with older literature. While we included any study that described the relationship of NMS to PO, few described their definition of PO, making it difficult to assess the correlation of PO magnitude to associated symptoms. Additionally, while we excluded studies primarily focused on surgical treatment outcomes, we opted to include older studies discussing populations of patients with both surgically and non-surgically; in some cases, the authors did not separate out these groups for analysis. This was done as many landmark papers for our understanding of PO natural history were among these studies. Without including several of these older, important articles, a thorough review of the impact of PO on NMS would not be possible given a lack of natural history studies in the modern era.

In summary, the pelvis serves as a linkage between the spine and the lower extremities, and tilting or obliquity of the pelvis is commonly observed in the neuromuscular population. While neutralizing PO is classically considered a major technical goal of spinal fusion for NMS, critical review of the literature reveals a lack of sound evidence showing that mild PO is not tolerable in the natural history of the disease. We found that any issues exist surrounding the measurement of PO. This review shows some support in the literature for the notion of increasing PO as a factor in seating difficulty in this population. While it may seem intuitive that having a straight spine and a level pelvis is preferable to severe scoliosis in patients with NMS, further studies with clearly defined endpoints and measures are needed to address these questions. "Seating" is a multidimensional concept that depends on motor strength and control, upper extremity function, balance, and the magnitude and flexibility of both infra- and supra-pelvic deformities which impact global positioning. We were unable to draw any solid conclusions regarding the magnitude of PO that impacts seating or function, perhaps due to the complex relationships noted above, the inability to define PO clinically or radiographically, and limitations in the number of functional outcome measures which evaluating seating. Future studies should focus on redefining PO within the context of global positioning, and newer outcome measures should be developed to assess seating.

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