Eur Spine J (2016) 25:2433–2441
DOI 10.1007/s00586-015-3759-7

ORIGINAL ARTICLE

Patients with spinal deformity over the age of 75: a retrospective analysis of operative versus non-operative management

Daniel M. Sciubba · Justin K. Scheer · Alp Yurter · Justin S. Smith · Virginie Lafage · Eric Klineberg · Munish Gupta · Robert Eastlack · Gregory M. Mundis · Themistocles S. Protopsaltis · Donald Blaskiewicz · Han Jo Kim · Tyler Koski · Khaled Kebaish · Christopher I. Shaffrey · Shay Bess · Robert A. Hart · Frank Schwab · Christopher P. Ames · the International Spine Study Group (ISSG)

Received: 21 September 2014 / Revised: 6 January 2015 / Accepted: 6 January 2015 / Published online: 6 February 2015

Abstract
Purpose The goal of the present study was to compare the outcomes of operative and non-operative patients with adult spinal deformity (ASD) over 75 years of age.
Methods A retrospective review of a multicenter prospective adult spinal deformity database was conducted examining patients with ASD over the age of 75 years. Demographics, comorbidities, operation-related variables, complications, radiographs, and Health-related quality of life (HRQOL) measures collected included Oswestry Disability Index, Short Form-36, and Scoliosis Research Society-22 preoperatively, and at 1 and 2 years later. Minimum clinically important difference (MCID) was calculated and also compared.
Results 27 patients (12 operative, 15 non-operative) were studied. There were no significant differences ($p > 0.05$) between operative and non-operative patients for age, body mass-index, and comorbidities, but operative patients had worse baseline HRQOL than non-operative patients. Operative patients had a significant improvement in radiographic parameters in 2-year HRQOL, whereas non-operative patients did not ($p > 0.05$). Operative patients were significantly more likely to reach MCID (range 41.7–81.8 vs. 0–33.3 %, $p < 0.05$). In the surgical group, 9 (75 %) patients had at least 1 complication (24 total complications).
Conclusions In the largest series to date comparing operative and non-operative management of adult spinal deformity in elderly patients greater than 75 years of age, reconstructive surgery provides significant improvements

D. M. Sciubba (✉) · A. Yurter
Department of Neurosurgery, The Johns Hopkins Hospital, 600 N. Wolfe St, Meyer 5-185, Baltimore, MD 21287, USA
e-mail: dsciubb1@jhmi.edu

J. K. Scheer · T. Koski
Department of Neurological Surgery, Northwestern University Feinberg School of Medicine, Chicago, IL, USA

J. S. Smith · C. I. Shaffrey
Department of Neurosurgery, University of Virginia Health System, Charlottesville, VA, USA

V. Lafage · T. S. Protopsaltis · F. Schwab
Department of Orthopaedic Surgery, NYU Hospital for Joint Diseases, New York, NY, USA

E. Klineberg · M. Gupta
Department of Orthopaedic Surgery, University of California, Davis, CA, USA

R. Eastlack · G. M. Mundis
San Diego Center for Spinal Disorders, La Jolla, CA, USA

D. Blaskiewicz
Neurosurgical Medical Clinic, San Diego, CA, USA

H. J. Kim
Department of Orthopaedic Surgery, Hospital for Special Surgery, New York, NY, USA

K. Kebaish
Department of Orthopaedic Surgery, Johns Hopkins University, Baltimore, MD, USA

S. Bess
Rocky Mountain Hospital for Children, Denver, CO, USA

R. A. Hart
Department of Orthopaedic Surgery, Oregon Health and Science University, Portland, OR, USA

C. P. Ames
Department of Neurological Surgery, University of California, San Francisco, San Francisco, CA, USA

in pain and disability over a 2-year period. Furthermore, operative patients were more likely to reach MCID than non-operative patients. When counseling elderly patients with ASD, such data may be helpful in the decision-making process regarding treatment.

Keywords Adult spinal deformity · Complications · Elderly · Non-operative · HRQOL · Scoliosis · 75 years · MCID

Introduction

Adult scoliosis has been found to occur with increasing frequency as patients age, with rates as high as 68 % in individuals over the age of 60 [1]. Although the majority of these individuals will not seek out medical attention for asymptomatic degenerative scoliosis, the increase in life expectancy of the general population will undoubtedly lead to more elderly patients presenting with spinal deformities seeking reconstructive surgery. Unfortunately, this older patient population also has substantially higher prevalence of chronic disease, which may make any moderate- to-large spinal operation risky [2]. For this reason, it is highly relevant during preoperative counseling to quantify the potential risks and benefits for the patients in this high risk group.

To date, numerous studies have shown that age is an independent risk factor for surgical complications in scoliosis [3–5]. In addition, not only surgical morbidity but also surgical mortality has been associated with older age following spinal surgery as well as differences in alignment [6–9]. However, other studies have shown that older patients may benefit the most from spinal deformity surgery as they often report worse baseline health-related quality of life (HRQOL), greater use of analgesics, and larger functional limitations compared to younger patients [10, 11]. For this reason, surgeons are in need of further data to help risk benefit tradeoffs for the elderly patient with spinal deformity.

In this study, a retrospective review of a multicenter prospective adult spinal deformity database was conducted to compare operative and non-operative management of patients over the age of 75 who presented with symptomatic adult scoliosis. Our hypothesis was that the operative patients would significantly benefit from operative treatment over non-operative treatment.

Methods

Patient population

This study is a retrospective review of a prospectively collected multicenter adult spinal deformity database. Patients were drawn from the International Spine Study Group (ISSG), which is composed of 11 sites across the United States. All patients were enrolled into an Institutional Review Board-approved protocol by each site. Inclusion criteria for the ISSG database were: age >18 years and presence of spinal deformity, as defined by scoliosis Cobb angle ≥20°, sagittal vertical axis (SVA) ≥5 cm, pelvic tilt (PT) ≥25°, and/or thoracic kyphosis (TK) ≥60°. Exclusion criteria included spinal deformity of a neuromuscular etiology and presence of active infection or malignancy. In addition to the database inclusion criteria, patients were included in the present study if (1) ≥4 spinal levels fused and (2) age at time of enrollment was 75 years or greater.

Patients were group based on operative and non-operative management. The decision to pursue operative management was determined between each individual surgeon and patient based on the patient's goal of care. This decision is very complex and the majority of ASD patients seen in our clinics have received non-operative treatment. They are being seen for possible surgical intervention. The patients presenting with a progressive neurologic compromise, myelopathy, or bowel/bladder incontinence are generally advised to pursue operative treatment. The remaining patients are counseled regarding operative and non-operative management options. In general, patients are encouraged to maximize non-operative treatments, such as physical therapy, steroid injections, and pharmacological therapy.

Data collection, radiographic assessment, and classification

Data collected included demographic data, Charlson comorbidity Index (CCI) surgical data, health-related-quality of life (HRQOL), comorbidities, complications, and reoperations.

Full-length free-standing lateral spine radiographs (36″ cassette) at baseline and 1- and 2-year follow-up were analyzed using validated software [12, 13] (Spineview®, ENSAM, Laboratory of Biomechanics, Paris, France). All radiographic measures were performed at a central location (NYU) based on standard techniques [14] and included: thoracic kyphosis (TK, T4-T12; Cobb angle between superior endplate of T4 and inferior endplate of T12) [15], lumbar lordosis (LL, Cobb angle between superior endplate of L1 and superior endplate of S1) [15], sagittal vertical axis (SVA, C7 plumbline relative to S1), pelvic tilt (PT), and mismatch between pelvic incidence [16, 17] and lumbar lordosis (PI-LL). Cervical radiographic measures included C2–C7 SVA (C2 plumbline relative to C7), C2–C7 lordosis (CL), T1 slope (T1S), and T1S minus CL (T1S-CL).

Based on the above radiographic parameters, patients were additionally stratified by the SRS-Schwab adult spinal deformity classification [18]. The classification is divided into the coronal curve type and sagittal modifiers. The coronal curve type is determined based on the maximal coronal angle measured according to standard Cobb technique. The 4 types include the following: Type T: patients with a thoracic major curve of greater than 30° (apical level of T9 or higher), Type L: patients with a lumbar or thoracolumbar major curve of greater than 30° (apical level of T10 or lower), type D: patients with a double major curve (one T and one L curves), with each curve greater than 30°, and type N: patients with no coronal curve greater than 30° (i.e., no major coronal deformity).

The HRQOL measures collected included pain assessment with an 11 point numerical rating scale (NRS), Oswestry Disability Index (ODI), Short Form-36 (SF36, PCS, and MCS), and Scoliosis Research Society (SRS22) and were obtained preoperatively, 1 year, and 2 years postoperatively. Differences and correlations between age groups for HRQOL at the standard preoperative time and follow-up time points were investigated. Furthermore, the change in HRQOL at the post-operative time points compared with pre-operative values was compared across surgery and age groups. In order to place HRQOL outcomes in a clinically relevant context, minimal clinically import difference (MCID) values have been established for the HRQOL instruments [19, 20]. Analysis for differences in the proportions of patients between operative and non-operative patients reaching MCID for each HRQOL measure was also considered. The MCID values used in the present study included: ODI (−15), PCS (+5.2), SRS Activity (+0.375), SRS Pain (+0.587), SRS Appearance (+0.8), and SRS Mental (+0.42) [19–22]. And lastly, SRS Activity, SRS Pain, SRS Appearance, and SRS Mental scores were compared to age- and sex-matched subjects from a large study of 1346 adult subjects without scoliosis [23].

Complications were recorded and included the number of intra-, peri-, and post-operative complications and associated number of revisions and reoperations. The specific type of complication was recorded and included implant failure, infection, neurologic, cardiopulmonary, vascular, gastrointestinal, operative, renal, wound problems, radiographic, and death. In addition, medical comorbidities were recorded.

Statistical analyses

Continuous variables were described with the mean and standard deviation (SD). Statistical analysis was performed using the Student's t test and the Wilcoxon rank sum or Kruskal–Wallis tests where appropriate. Patients were also compared to age- and sex-matched subjects without spinal deformity at baseline and 2 years for SRS Activity, SRS Pain, SRS Appearance, and SRS Mental. Frequency analysis used for categorical variables was carried out using the Fisher's Exact Test. All statistical analyses were conducted using commercially available software (JMP v7.0, SAS Institute, Inc., Cary, NC) and the level of significance was set at $p < 0.05$ for all.

Results

Patient population

51 patients met inclusion criteria and where eligible for 2-year follow-up, of which 27 (52.9 %) met baseline and 2-year clinical and radiographic follow-up: 12 operative and 15 non-operative (Table 1). Twenty four patients were excluded from the 51 eligible patients due to the following reasons: 10 were lost to follow-up, 7 withdrew from the study, 4 did not have complete baseline data, and 3 non-operative patients crossed over to operative management. 10 out of the 27 (37.0 %) were at least 80 years of age. The non-operative group had a significantly higher percentage of female patients. There were no significant differences between the operative patients and non-operative patients for age, BMI, CCI, and SRS-Schwab coronal curve Type ($p > 0.05$ for all). The majority of patients (59.3 %) were classified at baseline as SRS-Schwab coronal curve Type N (Table 1).

Comorbidities

Out of the total of 27 patients, 24 (88.9 %) had at least one comorbidity that ranged from 1 to 5. The number of patients with each type of comorbidityis listed in Table 2. The majority of patients had 2 or greater comorbidities (48.1 %). The top 5 most common comorbidities included leg weakness (66.7 %), numbness or tingling in legs (51.9 %), arthritis (48.1 %), hypertension (44.4 %), and osteoporosis (37.0 %).

Surgical data

Surgical characteristics are presented in Table 3. All 12 operative patients underwent a posterior-only approach and posterior instrumentation and fusion. The average length of stay (LOS) in days was 12.9 ± 3.7. Estimated blood loss (EBL) in mL was 2,416.7 ± 1,565.4. The levels fused ranged from 4 to 17 and the UIV and LIV levels ranged from T1 to T11 and L5-ilium, respectively. 11 out of 12 (91.7 %) patients underwent an osteotomy and 11 (91.7 %) had a decompression. Of note, 33.3 % of patients had a pedicle subtraction osteotomy (PSO), while 58.3 %

Table 1 Demographic data and baseline SRS-Schwab coronal curve types for patients ≥75 years of age

≥75 years of age	All	Operative	Non-operative	*p* value
Number of patients	27	12	15	
Age	78.5 ± 2.5	78 ± 2.3	78.9 ± 2.6	0.3497
Female:male	22:5	7:5	15:0	0.0049
BMI	28.7 ± 5.5	29.8 ± 7	27.9 ± 4.3	0.4465
CCI	2 ± 1.2	1.7 ± 1.2	2.3 ± 1.2	0.2718
Baseline SRS-schwab coronal				
Type N	16 (59.3 %)	6 (50 %)	10 (66.7 %)	0.3565
Type T	0 (0 %)	0 (0 %)	0 (0 %)	
Type L	10 (37 %)	5 (41.7 %)	5 (33.3 %)	
Type D	1 (3.7 %)	1 (8.3 %)	0 (0 %)	

BMI Body Mass Index, *CCI* Charlson Comorbidity Index, *Type T* patients with a thoracic major curve of greater than 30° (apical level of T9 or higher), *Type L* patients with a lumbar or thoracolumbar major curve of greater than 30° (apical level of T10 or lower), *Type D* patients with a double major curve, with each curve greater than 30°, *Type N* patients with no coronal curve greater than 30° (i.e., no major coronal deformity)

Percentages were calculated out of the total number of patients in each group, respectively. *p* values are for comparisons between operative and non-operative groups and those marked in bold with an (*) are significant ($p < 0.05$)

underwent a posterior element osteotomy (ponte or smith-peterson osteotomy, SPO).

Complications

The percentages listed are out of the total operative patients ($n = 12$, 100 %). 9 (75.0 %) patients had at least 1 complication with a total of 24 complications (11 major and 13 minor, Table 4). There were 3 (25.0 %) patients that had an intraoperative complication, 6 (50.0 %) with peri-operative, and 8 (66.7 %) with a post-operative complication. 6 patients (50.0 %) had a reoperation during the two-year follow-up period, of which 3 were for a revision. The 3 reoperation indications were coronal malalignment, radiculitis, and deep infection. The 3 revision indications were 2 rod fractures and 1 for PJK. The top 3 major complications included implant (25.0 %), operative (25.0 %), and radiographic (16.7 %, Table 4). The top 4 common minor complications included radiographic (25.0 %) and cardiopulmonary (25.0 %) neurologic (16.7 %), and gastrointestinal (16.7 %). There were neither wound complications nor deaths during the 2 year follow-up period.

Radiographic analysis

Means ± 1 SD are presented in Table 5. All baseline radiographic parameters were statistically similar between operative and non-operative patients ($p > 0.05$ for all). The operative patients had significantly lower 2-year PI-LL (7.5 ± 13.2 vs. 27 ± 13.9, $p = 0.0008$). In addition, the operative group had a significant improvement in TK ($p = 0.0047$), C7SVA ($p = 0.0056$), and PI-LL ($p = 0.0067$), at 2 years compared with preoperative values (Table 5). There were no significant differences between baseline and 2-year radiographic parameters for the non-operative patients ($p > 0.05$ for all).

HRQOL analysis

The mean SRS values for age- and sex-matched normal controls [23] used for comparison to the present study population were the following: SRS Activity (4.12 ± 0.02), SRS Pain (4.25 ± 0.05), SRS Appearance (4.17 ± 0.04), and SRS Mental (4.11 ± 0.06). All the patients, as well as within the operative and non-operative groups, had a significantly lower mean baseline and 2 year SRS Activity, SRS Pain, and SRS Appearance compared with the age- and sex-matched normal controls ($p < 0.05$ for all). In addition, the operative group had significantly worse baseline and 2 year SRS Mental than the age- and sex-matched normal controls ($p < 0.05$ for both).

The operative patients had worse baseline ODI ($p = 0.0096$), PCS ($p = 0.0034$), SRS Activity ($p = 0.0114$), SRS Appearance ($p = 0.0095$), and SRS Total ($p = 0.0097$) than the non-operative patients (Table 6). The operative group had significantly higher 2-year SRS Appearance ($p = 0.0306$) and 2-year SRS Satisfaction ($p = 0.0053$) than the non-operative patients. No other 2-year differences were noted ($p > 0.05$ for all). When compared to baseline values, the operative patients had significant improvement in 2 year ODI ($p = 0.0072$), PCS ($p = 0.0009$), SRS Activity ($p = 0.0104$), SRS Appearance ($p = 0.0011$), SRS Pain ($p = 0.0079$), SRS Satisfaction ($p = 0.0102$), and SRS Total ($p = 0.0014$). There were no significant differences between baseline and

Table 2 The number of patients with the listed number and types of comorbidities for all patients

Parameter	No. patients
≥1 comorbidity	24 (88.9 %)
No. of comorbidities	
0	3 (11.1 %)
1	4 (14.8 %)
2	13 (48.1 %)
3	2 (7.4 %)
4	4 (14.8 %)
5	1 (3.7 %)
Types	
Leg weakness	18 (66.7 %)
Numbness or tingling in legs	14 (51.9 %)
Arthritis	13 (48.1 %)
Hypertension	12 (44.4 %)
Osteoporosis	10 (37 %)
Bladder incontinence	7 (25.9 %)
Diabetes	5 (18.5 %)
Depression	4 (14.8 %)
Heart disease	4 (14.8 %)
Bowel incontinence	3 (11.1 %)
None	3 (11.1 %)
Cancer	3 (11.1 %)
Gastric ulcer	2 (7.4 %)
Anemia	1 (3.7 %)
Renal disease	1 (3.7 %)
Neurological	1 (3.7 %)
Psychiatric	1 (3.7 %)
Drug allergy	0 (0 %)
DVT	0 (0 %)
Liver disease	0 (0 %)
Pulmonary disease	0 (0 %)
Peripheral vascular disease	0 (0 %)

Percentages are out of the total 27 patients

Table 3 Surgical characteristics for patients ≥75 years of age

Parameter	Value
Number of patients	12 (100 %)
Age	78.1 ± 2.4
ASA	2.8 ± 0.4
LOS (days)	12.9 ± 3.7
OR time (min)	413.2 ± 157.8
EBL	2416.7 ± 1565.4
Posterior-only approach	12 (100 %)
Posterior instrumentation and fusion	12 (100 %)
Number of levels fused	4–17
UIV range	T1–T11
LIV range	L5-ilium
Osteotomy	11 (91.7 %)
PSO total	4 (33.3 %)
PSO L3	1
PSO L4	3
SPO (range 2–7 levels)	7 (58.3 %)
Interbody fusion	8 (66.7 %)
ALIF	3 (25.0 %)
XLIF	1 (8.3 %)
Decompression	11 (91.7 %)

Percentages are calculated from the total number of operative patients ($n = 12$)

ASA American Society of Anesthesiologists classification system, *LOS* length of stay, *OR* operating room, *EBL* estimated blood loss, *UIV* upper-most instrumented vertebra, *LIV* lower-most instrumented vertebra, *PSO* pedicle subtraction osteotomy, *SPO* smith-Peterson osteotomy, *ALIF* anterior lumbar interbody fusion, *XLIF* extreme lateral interbody fusion

2-year HRQOL for the non-operative patients ($p > 0.05$ for all). Furthermore, the operative patients were significantly more likely to reach MCID than the non-operative patients for PCS (66.7 vs. 14.3 %), SRS Activity (81.8 vs. 26.7 %), SRS Pain (81.8 vs. 33.3 %), and SRS Appearance (63.6 vs. 0.0 %, $p < 0.05$ for all, Table 7).

Discussion

We conducted a retrospective study comparing groups of elderly ASD patients who were treated non-operatively and operatively. Of the surgical cohort, 88.9 % had at least one comorbidity and 75 % had at least one complication. However, these patients had a greater improvement in outcomes than their non-operative counterpart, and this improvement was significant over 2 years. Therefore, this study suggests that the operative management of patients with spinal deformity over the age of 75 may be justified in a select group of patients despite a high comorbidity and complication rate. Our results are in agreement with a previous study in which Bridwell et al. [10] prospectively compared changes in HRQOL for non-operative and operative treatment of ASD over a 2-year follow-up period; the older surgical population (60–80 years) experienced significant HRQOL improvements following treatment, while its non-operative counterpart did not. Our data are valuable in the current environment, in which health care systems are trying to quantify the risks and benefits of various medical treatments or surgical interventions based on value obtained per cost [24].

With the global expansion of the elderly population (≥65 years), the demand for surgical treatment of adult spinal deformity will significantly increase, especially by 2030 [25]. Unfortunately, particularly in the context of ASD surgery, numerous studies correlate older age to a

Table 4 The number of patients with complications by timing and type

Parameter	Value	
Total number of complications	24	
Total number of major complications	11	
Total number of minor complications	13	
Complications related to index surgery	23	
Complications related to revision	1	
Complication parameter	**No. (%) of patients**	
≥1 complication (range 1–5)	9 (75)	
Intra-operative (total 1 each)	3 (25)	
Peri-operative (range 1–3)	6 (50)	
Post-operative (range 1–4)	8 (66.7)	
Revisions	3 (25)	
Reoperations	6 (50)	
Major	11 (91.7)	
Minor	13 (108.3)	
Complication types	**Major**	**Minor**
Implant	3 (25 %)	1 (8.3 %)
Operative	3 (25 %)	0 (0 %)
Radiographic	2 (16.7 %)	3 (25 %)
Infection	1 (8.3 %)	0 (0 %)
Cardiopulmonary	1 (8.3 %)	3 (25 %)
Gastrointestinal	1 (8.3 %)	2 (16.7 %)
Neurologic	0 (0 %)	2 (16.7 %)
Vascular	0 (0 %)	0 (0 %)
Renal	0 (0 %)	0 (0 %)
Wound problems	0 (0 %)	0 (0 %)
death	0 (0 %)	0 (0 %)

Percentages are out of the 12 operative patients

higher rate of morbidity and mortality [3, 4, 6, 8]. Elderly adults typically exhibit inferior bone quality and a greater degree of degeneration of various spinal structures, lengthening the operative time and increasing the risk of postoperative complications, especially pseudarthrosis, instrument-related failure, and proximal junctional kyphosis [3, 5, 26]. Moreover, patients over 50 are usually burdened with additional systemic diseases such as cardiovascular disease and diabetes, resulting in an increased risk for peri-operative medical complications [2].

Despite increased comorbidities and surgical risks, elderly patients often have worse baseline HRQOL measures and thus may benefit more significantly from surgery than younger patients. For example, in a retrospective cohort study assessing improvements in HRQOL for operative treatment of ASD, Smith et al. [11] found that, in comparison to the younger population (25–44 years), the older population (65–85 years) started with lower baseline QOL scores and experienced significant improvements with respect to ODI and leg pain numerical rating scale (NRS), as well as a trend toward greater improvements with respect to SF-12 PCS, SRS-22, and back pain NRS.

The present study suggests operative treatment may benefit select elderly patients with ASD by decreasing disability and increasing health status, however, it is important to note that some elderly patients may be poor surgical candidates due to being too unhealthy, having very poor bone quality, or having a lack of a sufficient social support. Thus, the elderly patients that do undergo surgical intervention are a select group despite the high comorbidity rates. They present with worse baseline HRQOL than the non-operative patients and therefore were likely operated on as a result. Although the populations may be different, it is clear throughout the literature that operative patients have worse baseline HRQOL and disability than non-operative patients and thus this does not invalidate the comparison [10, 27–31]. Furthermore, we do not necessarily advocate operative management for all elderly patients with symptomatic ASD. Non-operative methods should be attempted first and all means exhausted before the discussion of surgery intervention. During this discussion, several key factors should be considered, including the severity of the patient's symptoms, the impact of these symptoms on function and quality of life, the overall health of the patient, and the willingness of the patient to accept the risks of surgery. The complication rate is much higher in the elderly following ASD surgery [32–35] and patients should understand the associated complications and their respective treatments before proceeding.

There are limitations in this study worth mentioning such as patients lost to follow-up. The retrospective nature of this study inherently diminishes the quality of the data; the lack of prospective randomization with regard to treatment selection (operative vs. non-operative) may have created biased cohorts. Specifically, surgeons may have selected patients that they deemed suitable for surgery or patients may have self-selected themselves for or against surgery. Moreover, the relatively small patient population restricts the statistical power of the results obtained, especially with respect to the magnitude of the risk–benefit ratio for surgery (i.e., number of complications and complication rate versus improvements in HRQOL measures). It also restricts the ability to identify certain patients that are candidates for operative treatment beyond the radiographic indication. Future work with larger studies may provide the means to assess this. And lastly, this study did not account for compensatory mechanisms in either cohort, which may also provide valuable differences in these populations [36, 37].

Table 5 Means ± 1 SD of all radiographic parameters at baseline, 1 and 2 years for patients ≥75 years of age

Time	Group	T1S	CL	T1S-CL	C2C7 SVA (mm)	TK	PT	C7–S1 SVA (mm)	PI-LL
Baseline	All (*n* = 27)	32.8 ± 13.3	10.4 ± 13.8	18.2 ± 11.2	36.1 ± 20.5	38.3 ± 19.7	30.2 ± 9.4	105.4 ± 74.1	23.7 ± 15.4
	Operative (*n* = 12)	33.5 ± 12.7	15.6 ± 14.8	17.1 ± 13.4	43 ± 15.7	29.1 ± 21.8	28.4 ± 11.1	156.5 ± 48.9	31.6 ± 20
	Non-operative (*n* = 15)	32.2 ± 14.5	8 ± 16.1	17.6 ± 13.4	36.9 ± 23.5	38.3 ± 20.7	30.5 ± 9.9	100.9 ± 78	23.4 ± 13.6
	p value (OP vs NONOP)	0.5582	0.3272	0.9025	0.6242	0.2831	0.5914	0.0570	0.1073
2 year	All (*n* = 27)	38.5 ± 15	17.3 ± 16.5	21.6 ± 14.9	40.4 ± 23.4	41.2 ± 21.6	28.7 ± 10	119.1 ± 81.3	23.5 ± 17.3
	Operative (*n* = 12)	40.9 ± 13.9	9.6 ± 24.6	30.5 ± 18.3	52.1 ± 22.7	55.2 ± 14.2	22.9 ± 8.7	82.8 ± 58.4	8.7 ± 15
	Non-operative (*n* = 15)	39.4 ± 15.2	20.5 ± 15	19.3 ± 13.2	40.5 ± 20.3	39.5 ± 23.1	30 ± 9.9	131.8 ± 80.7	27 ± 13.9
	p value (2 years OP vs 2 years NONOP)	0.8267	0.3522	0.1769	0.1021	0.0637	0.1021	0.1546	**0.0034***
	p value 2 years vs baseline OP	0.2954	0.5967	0.1416	0.1208	**0.0047***	0.1396	**0.0056***	**0.0067***
	p value 2 years vs baseline NONOP	0.2217	0.257	0.5271	0.7518	0.9174	0.8519	0.4321	0.5201

OP patients that underwent operative treatment, *NONOP* patients that underwent non-operative treatment, *T1S* T1 slope, *CL* cervical lordosis, *SVA* sagittal vertical axis, *TK* thoracic kyphosis, *LL* lumbar lordosis, *PT* pelvic tilt, *PI-LL* the mismatch between pelvic incidence (PI) and lumbar lordosis

p values marked in bold and with an (*) are significant ($p < 0.05$)

Table 6 Means ± 1 SD of all health-related quality of life measures at baseline, 1 and 2 years for patients ≥75 years of age

Time	Group	ODI	PCS	MCS	SRS Activity	SRS Pain	SRS Appearance	SRS Mental	SRS Satisfaction	SRS Total
Baseline	All (*n* = 27)	39.8 ± 13.2	32 ± 7.8	50.5 ± 7.6	3.2 ± 0.7	2.7 ± 0.9	3 ± 0.7	3.8 ± 0.7	3.7 ± 0.8	3.2 ± 0.6
	Operative (*n* = 12)	51.7 ± 12.5	23.6 ± 5.8	51 ± 13.1	2.5 ± 0.7	2.2 ± 0.7	2.3 ± 0.7	3.5 ± 0.9	3.1 ± 1.2	2.7 ± 0.6
	Non-operative (*n* = 15)	37.5 ± 12.9	32.6 ± 8.2	50.5 ± 8	3.3 ± 0.7	2.9 ± 0.9	3.1 ± 0.6	3.9 ± 0.7	3.7 ± 0.7	3.3 ± 0.6
	p value (OP vs NONOP)	**0.0096***	**0.0034***	0.8153	**0.0114***	0.0697	**0.0095***	0.2594	0.0981	**0.0097***
2 year	All (*n* = 27)	42.1 ± 19.2	31.1 ± 7.4	51 ± 13.5	3.2 ± 0.7	3 ± 1	2.9 ± 0.8	3.8 ± 0.9	3.7 ± 1.1	3.3 ± 0.7
	Operative (*n* = 12)	32.1 ± 19.3	35.9 ± 8.3	49.7 ± 12	3.5 ± 0.7	3.6 ± 1.1	3.6 ± 0.7	3.8 ± 0.8	4.6 ± 0.9	3.7 ± 0.7
	Non-operative (*n* = 15)	42.1 ± 20.4	30.7 ± 7.7	51.5 ± 13.8	3.1 ± 0.7	3 ± 1	2.8 ± 0.8	3.8 ± 0.9	3.6 ± 1	3.2 ± 0.7
	p value (2 years OP vs 2 years NONOP)	0.2938	0.1977	0.6395	0.1663	0.2628	**0.0306***	0.9584	**0.0053***	0.1019
	p value 2 years vs baseline OP	**0.0072***	**0.0009***	0.7248	**0.0104***	**0.0079***	**0.0011***	0.4593	**0.0102***	**0.0014***
	p value 2 years vs baseline NONOP	0.8028	0.5705	0.6945	0.6468	0.589	0.2436	0.9834	0.8653	0.7873

OP patients that underwent operative treatment, *NONOP* patients that underwent non-operative treatment, *NRS* numerical rating scale, *ODI* Oswestry Disability Index, *PCS* physical component score from the Short Form-36, *MCS* mental component score from the Short Form-36, *SRS* Scoliosis Research Society

p values marked in bold and with an (*) are significant ($p < 0.05$)

Table 7 The percentage of patients that reached minimum clinically important difference (MCID) from baseline to 2 years post-operative for Oswestry disability index (ODI), physical component score (PCS) from the SF36, and the Scoliosis Research Society (SRS) questionnaire

MCID	All	Operative	Non-operative	*p* value
Number of patients	27	12	15	
ODI	25.9 %	41.7 %	13.3 %	0.0930
PCS	34.8 %	66.7 %	14.3 %	**0.0092***
SRS Activity	50.0 %	81.8 %	26.7 %	**0.0042***
SRS Pain	53.8 %	81.8 %	33.3 %	**0.0117***
SRS Appearance	26.9 %	63.6 %	0.0 %	**0.0001***
SRS Mental	23.1 %	27.3 %	20.0 %	0.6649

p values are for comparisons between operative and non-operative groups and those marked in bold with an (*) are significant ($p < 0.05$)

Conclusion

In the largest series to date comparing operative and non-operative management of adult spinal deformity in elderly patients greater than 75 years of age, reconstructive surgery can provide significant improvements in pain and disability over a two-year period. When compared to a similar cohort of elderly patients managed non-operatively over a similar time period, patients undergoing surgery had significantly improved HRQOL measures over baseline values and compared to the non-operative cohort, despite substantial operative morbidity. Furthermore, operative patients were more likely to reach MCID than non-operative patients. When counseling elderly patients with ASD, such data may be used to prognosticate for this complicated age group.

Acknowledgments Funding for the International Spine Study Group Foundation, through which this study was conducted, is funded through research grants from DePuy Spine and individual donations.

Conflict of interest None of the authors have a conflict of interest with this manuscript.

References

1. Pekmezci M, Berven SH, Hu SS, Deviren V (2009) The factors that play a role in the decision-making process of adult deformity patients. Spine (Phila Pa 1976) 34:813–817. doi:10.1097/BRS.0b013e3181851ba6
2. Aebi M (2005) The adult scoliosis. Eur Spine J Off Publ Eur Spine Soc Eur Spinal Deform Soc Eur Sect Cerv Spine Res Soc 14:925–948. doi:10.1007/s00586-005-1053-9
3. Kim YJ, Bridwell KH, Lenke LG, Rinella AS, Edwards C 2nd (2005) Pseudarthrosis in primary fusions for adult idiopathic scoliosis: incidence, risk factors, and outcome analysis. Spine (Phila Pa 1976) 30:468–474
4. Lippman CR, Spence CA, Youssef AS, Cahill DW (2003) Correction of adult scoliosis via a posterior-only approach. Neurosurg Focus 14:e5
5. Takahashi S, Delecrin J, Passuti N (2002) Surgical treatment of idiopathic scoliosis in adults: an age-related analysis of outcome. Spine (Phila Pa 1976) 27:1742–1748
6. Oldridge NB, Yuan Z, Stoll JE, Rimm AR (1994) Lumbar spine surgery and mortality among Medicare beneficiaries, 1986. Am J Public Health 84:1292–1298
7. Raffo CS, Lauerman WC (2006) Predicting morbidity and mortality of lumbar spine arthrodesis in patients in their ninth decade. Spine (Phila Pa 1976) 31:99–103
8. Schoenfeld AJ, Ochoa LM, Bader JO, Belmont PJ Jr (2011) Risk factors for immediate postoperative complications and mortality following spine surgery: a study of 3475 patients from the National Surgical Quality Improvement Program. J Bone Joint Surg Am 93:1577–1582. doi:10.2106/JBJS.J.01048
9. Roussouly P, Labelle H, Rouissi J, Bodin A (2013) Pre- and post-operative sagittal balance in idiopathic scoliosis: a comparison over the ages of two cohorts of 132 adolescents and 52 adults. Eur Spine J Off Publ Eur Spine Soc Eur Spinal Deform Soc Eur Sect Cerv Spine Res Soc 22(Suppl 2):S203–S215. doi:10.1007/s00586-012-2571-x
10. Bridwell KH, Glassman S, Horton W, Shaffrey C, Schwab F, Zebala LP, Lenke LG, Hilton JF, Shainline M, Baldus C, Wootten D (2009) Does treatment (nonoperative and operative) improve the two-year quality of life in patients with adult symptomatic lumbar scoliosis: a prospective multicenter evidence-based medicine study. Spine (Phila Pa 1976) 34:2171–2178. doi:10.1097/BRS.0b013e3181a8fdc8
11. Smith JS, Shaffrey CI, Glassman SD, Berven SH, Schwab FJ, Hamill CL, Horton WC, Ondra SL, Sansur CA, Bridwell KH, Spinal Deformity Study G (2011) Risk-benefit assessment of surgery for adult scoliosis: an analysis based on patient age. Spine (Phila Pa 1976) 36:817–824. doi:10.1097/BRS.0b013e3181e21783
12. Champain S, Benchikh K, Nogier A, Mazel C, Guise JD, Skalli W (2006) Validation of new clinical quantitative analysis software applicable in spine orthopaedic studies. Eur Spine J Off Publ Eur Spine Soc Eur Spinal Deform Soc Eur Sect Cerv Spine Res Soc 15:982–991. doi:10.1007/s00586-005-0927-1
13. Rillardon L, Levassor N, Guigui P, Wodecki P, Cardinne L, Templier A, Skalli W (2003) Validation of a tool to measure pelvic and spinal parameters of sagittal balance. Rev Chir Orthop Reparatrice Appar Mot 89:218–227
14. O'Brien MF, Kuklo TR, Blanke KM, Lenke LG (eds) (2005) Spinal Deformity Study Group Radiographic Measurement Manual. Medtronic Sofamor Danek, Inc., Minneapolis, MN
15. Roussouly P, Pinheiro-Franco JL (2011) Sagittal parameters of the spine: biomechanical approach. Eur Spine J Off Publ Eur Spine Soc Eur Spinal Deform Soc Eur Sect Cerv Spine Res Soc 20(Suppl 5):578–585. doi:10.1007/s00586-011-1924-1
16. Legaye J, Duval-Beaupere G, Hecquet J, Marty C (1998) Pelvic incidence: a fundamental pelvic parameter for three-dimensional regulation of spinal sagittal curves. Eur Spine J Off Publ Eur Spine Soc Eur Spinal Deform Soc Eur Sect Cerv Spine Res Soc 7:99–103
17. Roussouly P, Pinheiro-Franco JL (2011) Biomechanical analysis of the spino-pelvic organization and adaptation in pathology. Eur Spine J Off Publ Eur Spine Soc Eur Spinal Deform Soc Eur Sect Cerv Spine Res Soc 20(Suppl 5):609–618. doi:10.1007/s00586-011-1928-x
18. Schwab F, Ungar B, Blondel B, Buchowski J, Coe J, Deinlein D, DeWald C, Mehdian H, Shaffrey C, Tribus C, Lafage V (2012) Scoliosis Research Society-Schwab adult spinal deformity classification: a validation study. Spine 37:1077–1082. doi:10.1097/BRS.0b013e31823e15e2
19. Blondel B, Schwab F, Ungar B, Smith J, Bridwell K, Glassman S, Shaffrey C, Farcy JP, Lafage V (2012) Impact of magnitude and

percentage of global sagittal plane correction on health-related quality of life at 2-years follow-up. Neurosurgery 71:341–348. doi:10.1227/NEU.0b013e31825d20c0 (discussion 348)
20. Glassman SD, Copay AG, Berven SH, Polly DW, Subach BR, Carreon LY (2008) Defining substantial clinical benefit following lumbar spine arthrodesis. J Bone Joint Surg Am 90:1839–1847. doi:10.2106/JBJS.G.01095
21. Carreon LY, Sanders JO, Diab M, Sucato DJ, Sturm PF, Glassman SD, Spinal Deformity Study G (2010) The minimum clinically important difference in Scoliosis Research Society-22 Appearance, Activity, And Pain domains after surgical correction of adolescent idiopathic scoliosis. Spine 35:2079–2083. doi:10.1097/BRS.0b013e3181c61fd7
22. Copay AG, Glassman SD, Subach BR, Berven S, Schuler TC, Carreon LY (2008) Minimum clinically important difference in lumbar spine surgery patients: a choice of methods using the Oswestry Disability Index, Medical Outcomes Study questionnaire Short Form 36, and pain scales. Spine J Off J North Am Spine Soc 8:968–974. doi:10.1016/j.spinee.2007.11.006
23. Baldus C, Bridwell K, Harrast J, Shaffrey C, Ondra S, Lenke L, Schwab F, Mardjetko S, Glassman S, Edwards C 2nd, Lowe T, Horton W, Polly D Jr (2011) The Scoliosis Research Society Health-Related Quality of Life (SRS-30) age-gender normative data: an analysis of 1346 adult subjects unaffected by scoliosis. Spine (Phila Pa 1976) 36:1154–1162. doi:10.1097/BRS.0b013e3181fc8f98
24. McCarthy I, O'Brien M, Ames C, Robinson C, Errico T, Polly DW Jr, Hostin R, International Spine Study G (2014) Incremental cost-effectiveness of adult spinal deformity surgery: observed quality-adjusted life years with surgery compared with predicted quality-adjusted life years without surgery. Neurosurg Focus 36:E3. doi:10.3171/2014.3.FOCUS1415
25. Schwab F, Dubey A, Gamez L, El Fegoun AB, Hwang K, Pagala M, Farcy JP (2005) Adult scoliosis: prevalence, SF-36, and nutritional parameters in an elderly volunteer population. Spine (Phila Pa 1976) 30:1082–1085
26. Bradford DS (1988) Adult scoliosis. Current concepts of treatment. Clin Orthop Relat Res (229):70–87
27. Li G, Passias P, Kozanek M, Fu E, Wang S, Xia Q, Li G, Rand FE, Wood KB (2009) Adult scoliosis in patients over sixty-five years of age: outcomes of operative versus nonoperative treatment at a minimum two-year follow-up. Spine (Phila Pa 1976) 34:2165–2170. doi:10.1097/BRS.0b013e3181b3ff0c
28. Liu S, Schwab F, Smith JS, Klineberg E, Ames CP, Mundis G, Hostin R, Kebaish K, Deviren V, Gupta M, Boachie-Adjei O, Hart RA, Bess S, Lafage V (2014) Likelihood of reaching minimal clinically important difference in adult spinal deformity: a comparison of operative and nonoperative treatment. Ochsner J 14:67–77
29. Smith JS, Shaffrey CI, Berven S, Glassman S, Hamill C, Horton W, Ondra S, Schwab F, Shainline M, Fu KM, Bridwell K, Spinal Deformity Study G (2009) Operative versus nonoperative treatment of leg pain in adults with scoliosis: a retrospective review of a prospective multicenter database with two-year follow-up. Spine (Phila Pa 1976) 34:1693–1698. doi:10.1097/BRS.0b013e3181ac5fcd
30. Smith JS, Shaffrey CI, Berven S, Glassman S, Hamill C, Horton W, Ondra S, Schwab F, Shainline M, Fu KM, Bridwell K, Spinal Deformity Study G (2009) Improvement of back pain with operative and nonoperative treatment in adults with scoliosis. Neurosurgery 65:86–93. doi:10.1227/01.NEU.0000347005.35282.6C (discussion 93–84)
31. Terran J, Schwab F, Shaffrey CI, Smith JS, Devos P, Ames CP, Fu KM, Burton D, Hostin R, Klineberg E, Gupta M, Deviren V, Mundis G, Hart R, Bess S, Lafage V, International Spine Study G (2013) The SRS-Schwab adult spinal deformity classification: assessment and clinical correlations based on a prospective operative and nonoperative cohort. Neurosurgery 73:559–568. doi:10.1227/NEU.0000000000000012
32. Acosta FL Jr, McClendon J Jr, O'Shaughnessy BA, Koller H, Neal CJ, Meier O, Ames CP, Koski TR, Ondra SL (2011) Morbidity and mortality after spinal deformity surgery in patients 75 years and older: complications and predictive factors. J Neurosurg Spine 15:667–674. doi:10.3171/2011.7.SPINE10640
33. Hassanzadeh H, Jain A, El Dafrawy MH, Ain MC, Mesfin A, Skolasky RL, Kebaish KM (2012) Three-column osteotomies in the treatment of spinal deformity in adult patients 60 years old and older: outcome and complications. Spine (Phila Pa 1976) 38:726–731
34. Daubs MD, Lenke LG, Cheh G, Stobbs G, Bridwell KH (2007) Adult spinal deformity surgery: complications and outcomes in patients over age 60. Spine (Phila Pa 1976) 32:2238–2244. doi:10.1097/BRS.0b013e31814cf24a
35. Smith JS, Sansur CA, Donaldson WF 3rd, Perra JH, Mudiyam R, Choma TJ, Zeller RD, Knapp DR Jr, Noordeen HH, Berven SH, Goytan MJ, Boachie-Adjei O, Shaffrey CI (2011) Short-term morbidity and mortality associated with correction of thoracolumbar fixed sagittal plane deformity: a report from the Scoliosis Research Society Morbidity and Mortality Committee. Spine 36:958–964. doi:10.1097/BRS.0b013e3181eabb26
36. Barrey C, Roussouly P, Le Huec JC, D'Acunzi G, Perrin G (2013) Compensatory mechanisms contributing to keep the sagittal balance of the spine. Eur Spine J Off Publ Eur Spine Soc Eur Spinal Deform Soc Eur Sect Cerv Spine Res Soc 22(Suppl 6):S834–S841. doi:10.1007/s00586-013-3030-z
37. Barrey C, Roussouly P, Perrin G, Le Huec JC (2011) Sagittal balance disorders in severe degenerative spine. Can we identify the compensatory mechanisms? Eur Spine J Off Publ Eur Spine Soc Eur Spinal Deform Soc Eur Sect Cerv Spine Res Soc 20(Suppl 5):626–633. doi:10.1007/s00586-011-1930-3