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ADULT SPINAL DEFORMITY
Imaging, diagnostics and outcome

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ACADEMIC DISSERTATION

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LIST OF ORIGINAL PUBLICATIONS

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I Kyrölä KK, Järvenpää S, Järviluoma T, Irmola T, Kauppinen E, Häkkinen A. Intra- and interrater reliability of sagittal spinopelvic parameters on full-spine radiographs in adults with symptomatic spinal disorders. Neurospine 2018;15(2):175-181.

II Kyrölä K, Järvenpää S, Ylinen J, Mecklin JP, Repo JP, Häkkinen A. Reliability and validity study of the Finnish adaptation of Scoliosis Research Society Questionnaire version SRS-30. Spine (Phila P 1976) 2017;42(12):943-949.

III Kyrölä K, Repo J, Mecklin JP, Ylinen J, Kautiainen H, Häkkinen A. Spinopelvic changes based on the simplified SRS-Schwab adult spinal deformity classification: Relationships with disability and health related quality of life in adult patients with prolonged degenerative spinal disorders. Spine (Phila Pa 1976) 2018;43(7):497-502.

IV Kyrölä K, Kautiainen H, Pekkanen L, Mäkelä P, Kiviranta I, Häkkinen A. Long-term clinical and radiographic outcomes and patient satisfaction after adult spinal deformity correction. Scand J Surg 2018;Nov 19: 1457496918812201. doi: 10.1177/1457496918812201. [Epub ahead of print]

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ABBREVIATIONS

AIS	Adolescent idiopathic scoliosis
ALIF	Anterior lumbar interbody fusion
ANOVA	One-way analysis of variance
AP	Anterior-posterior imaging view of a radiograph
ASA	American society of anaesthesiologists
ASD	Adult spinal deformity
C2 (3,4…7)	Cervical vertebra n:o 2 (C3 cervical vertebra n:o 3 etc.)
CCA	Craniocervical angle
CBVA	Chin-brow vertical angle (°)
CI	Confidence interval
CL	Cervical Lordosis C2-C7 (°)
CPL	C2-C7 plumbline, mm or cm
CPT	The C2-pelvic tilt
CR	Coefficient of repeatability
cSVA	C2-C7 sagittal vertical axis
DSD	Degenerative segment disease
EQ-5D	EuroQol-5D measure of health status from the EuroQoL Group
EBL	Estimated blood loss
HRQoL	Health-Related Quality of Life
ICC	Intraclass correlation coefficient
IQR	Inter-quartile range
L1 (2,3…6)	Lumbar vertebra n:o 1 (Lumbar vertebra n:o 2 etc.)
LDI	Lordosis distribution index
LIV	Lowest instrumented vertebra
LL	Lumbar lordosis (°)
LS	Lumbosacral
mAs	Micro amper second (electric charge)
MRI	Magnetic resonance imaging
NSAID	Non-steroidal anti-inflammatory drug
ODI	Oswestry Disability Index
OR	Odds ratio
PA	Posterior-anterior imaging view of a radiograph

PACS	Picture archiving and communication system
PEEK	Polyether-ether ketone
PI	Pelvic incidence (°)
PI-LL	PI minus LL (°)
PJF	Proximal junctional failure (°)
PJK	Proximal junctional kyphosis (°)
PRO(M)	Patient reported outcome (measure)
PSO	Pedicle subtraction osteotomy
PT	Pelvic tilt (°)
RLL	Relative lumbar lordosis
QALE	Quality-adjusted life expectancy
QALY	Quality-adjusted life year
SDC	Smallest detectable change
SEM	Standard error of measurement
SF-36	Short-Form 36 questionnaire
SPO	Smith-Petersen osteotomy
SRS-22	Scoliosis Research Society Questionnaire version 22
SRS-30	Scoliosis Research Society Questionnaire version 30
SS	Sacral slope (°)
SVA	Sagittal vertical axis C7-S1, mm or cm
T1 (2,3...12)	Thoracic vertebra n:o 1 (T2= vertebra n:o 2 etc.)
T1/T9 SPi	T1 or T9 spinopelvic inclination °
THA	Total hip arthroplasty
TK	Thoracal kyphosis (°)
TKA	Total knee arthroplasty
TL	Thoracolumbar
TPA	T1 pelvic angle (°)
TS	T1-slope upper endplate obliquity (°)
TS-CL	T1-slope minus cervical lordosis
UIV	Upper instrumented vertebra
VCR	Vertebral column resection
2D, 3D	Two-dimensional, three-dimensional
3CO	Three-column osteotomy

ABSTRACT

Background

Back pain originating from multiple spinal disorders is the leading cause of disability worldwide. Adult spinal deformity (ASD) is a complex three-dimensional entity of multiple anatomical and functional disorders and predisposes to decreased health-related quality of life (HRQoL). With rising life expectancy and a growing elderly population it is predicted that an increasing number of symptomatic ASD patients will need surgical treatment. It is noteworthy that the prevalence of different grades of ASD, impact on HRQoL and patient-reported outcome (PRO) of ASD surgery has not earlier been reported in the Finnish population.

The aims of this study were to assess the reliability and repeatability of radiographic diagnostic imaging of ASD and to produce a culturally adapted and valid Finnish version of the Scoliosis Research Society (SRS) Questionnaire version 30 for spinal deformities. Thereafter the prevalence of ASD, applicability of a simplified version of the SRS-Schwab ASD classification and the Finnish SRS-30 were evaluated in a symptomatic adult patient cohort with prolonged degenerative spinal disorders. Finally, the long-term outcome, complications, patient satisfaction and predictive factors for poor outcome of ASD surgery, were investigated.

Methods

Over one year, a consecutive cohort of adult patients was recruited to Studies I-III after referral to the Central Hospital of Central Finland spine clinic due to prolonged degenerative spinal disease. 637 patients returned the completed HRQoL questionnaires and digital full spine radiographs were obtained. The radiographs of 49 patients were randomly selected for the reliability assessment, and a repeatability study of sagittal spinopelvic measurements with basic software tools was performed by three raters differing in their experience of image rating. The SRS-30 underwent translation and cross-cultural adaptation into Finnish and was subsequently validated and psychometrically tested among 274 patients. The SRS-Schwab ASD classification was graded and simplified dividing into mild, moderate and marked groups. The division was tested along with the Finnish SRS-30 questionnaire during evaluation of the prevalence and HRQoL of patients with sagittal malalignment among symptomatic adult patients with spinal degenerative disease but no pre-known deformity. The 79 patients in Study IV were operated during 2007-2016 in our clinic. The clinical and radiographic outcome, patient satisfaction, predictive factors for poor outcome and complications were analysed using the diagnostic tools renovated and tested in Studies I-III.

Results

The intra-and interrater reliability of the sagittal spinopelvic measurements proved reliable and repeatable with intraclass correlation coefficients (ICC) between 0.78-

0.99 and standard error of measurement (SEM) of 0.80-6.2° or 2.2-5.8mm. Greater rater experience in performing the radiographic measurements decreases, and greater complexity of the measurement landmarks increases, intra- and inter-rater bias.

The reproducibility and internal consistency (ICC 0.905, SEM 0.17, Cronbach α 0.885) of the Finnish version of the SRS-30 was good. The SRS-30 had discriminative validity in the pain, self-image and satisfaction with management domains compared with other questionnaires. A statistically significant difference between the moderate and marked deformity groups in the SRS-30 domains of function/activity (p=0.022) and self-image/appearance (p=0.016) was found.

Of the 637 patients in the consecutive cohort, 25% had moderate and 11% marked spinal deformities. The patients with marked deformity were significantly older, more overweight and more physically inactive than the others in the study population. The 3-class categorization of the SRS-Schwab ASD classification determined well the severity of sagittal deformity and concomitant loss of function, activity (p=0.004), and self-image/appearance (p=0.030) measured with the SRS-30, and disability with the ODI (p=0.033).

ASD operation decreased disability (ODI) and pain (VAS) significantly (p=0.001). Postoperative improvement in radiographic sagittal parameters was significant and maintained at 4-5 years of follow-up (p≤0.001). The mechanical failure of instrumentation of bone resulted in reoperation risk of 13.9% within the first and 29.8% during the 5-year follow-up. According to SRS-30, 49 (62.0%) patients were satisfied or very satisfied with the treatment and 57 (72.1%) would have the same operation again. Depression predicted poor outcome with an odds ratio of 6.97 (p=0.018).

Conclusions

The study comprised an unselected consecutive cohort of adult patients with prolonged degenerative spinal diseases, and thus the results can be generalized. Rater experience had a positive influence on the otherwise good reliability and repeatability of the spinopelvic measurements taken from full spine radiographs. The deformity-specific Finnish SRS-30 translation proved reliable and valid among the study cohort. The simplified categories of the SRS-Schwab ASD classification can detect different grades of deformity and related loss of HRQoL. Long-term radiographic and patient-reported clinical outcomes after the ASD surgery remained significantly better than preoperative scores. Risk for reoperation was highest during the first postoperative year. However good patient satisfaction and outcomes could be achieved irrespective of adverse effects. Depression was the only significant predictive factor for poor outcome after ASD surgery.

Keywords: adult spinal deformity, ASD, scoliosis, kyphosis, full-spine radiograph, reliability, repeatability, validation, outcome, health-related quality of life, Scoliosis Research Society questionnaire 30, SRS-30, SRS-Schwab ASD classification, spine surgery, pelvic incidence, pelvic tilt, sagittal vertical axis, lumbar lordosis, thoracic kyphosis

TIIVISTELMÄ

Tausta

Eri syistä johtuva selkäkipu on johtava toimintakykyhaitan aiheuttaja maailmassa. Aikuisen selän ryhtimuutos on anatomisten ja toiminnallisten muutosten aiheuttama kompleksi kolmiulotteinen kokonaisuus joka on yhteydessä heikentyneeseen terveyteen liittyvään elämänlaatuun (HRQoL). Rappeutumaan liittyvät ryhtimuutokset lisääntyvät iän mukana. Kasvanut eliniän odote ja iäkäs väestö ennustavat myös selän ryhtihäiriöiden kirurgisen hoidon tarpeen kasvua. Eri asteisten ryhtihäiriöiden esiintyvyyttä, vaikutusta elämänlaatuun tai leikkaushoidon tuloksia Suomessa ei ole aiemmin julkaistu. Myös suomenkielinen nimikkeistö kuvaamaan ryhtivirheitä on vakiintumatonta.

Tutkimuksen tavoite oli tutkia koko rangan röntgenkuvasta mitattujen etu-takasuunnnan sagittaalista ryhtihäiriötä kuvaavien muuttujien luotettavuutta ja toistettavuutta sekä tuottaa suomalaisille rangan ryhtihäiriöpotilaille sovitettu pätevä tulosmittari: Scoliosis Research Society (SRS) kysely versio 30. Jatkossa tutkittiin selän ryhtimuutosten esiintyvyyttä, yksinkertaistetun SRS-Schwab ryhtivirheluokittelun ja SRS-30 kyselyn soveltuvuutta aikuispotilailla, joilla oli pitkittynyt rappeutumaan liittyvä selkä-alaraajakipuoireisto. Lopuksi arvioitiin ryhtiä korjaavan kirurgian pitkäaikaistuloksia, komplikaatioita, potilastyytyväisyyttä ja leikkauksen tulosta ennustavia tekijöitä.

Menetelmät

Tutkimusjoukko osatöihin I-III kerättiin vuoden aikana Keski-Suomen keskussairaalan selkäyksikköön pitkittyneen rappeutuman aiheuttaman selkäkivun vuoksi lähetetyistä 874 potilaan joukosta. 637 potilasta täytti hyväksytysti kaikki kyselylomakkeet ja heistä otettiin koko rangan röntgenkuva. Sagittaalisuunnan ranka-lantio-muuttujien mittausten luotettavuus ja toistettavuus röntgenohjelman perustyökaluilla tutkittiin satunnaisista 49 kuvasta kolmen eri kokemuksen omaavan mittaajan toimesta. SRS-30 suomenkielinen käännös vahvistettiin päteväksi ja testattiin psykometrisesti 274 potilaalla. SRS-Schwab ryhtivirheluokittelu pisteytettiin ja yksinkertaistettiin jakamalla lieviin, kohtalaisiin ja vaikeisiin ryhmiin. Ryhmät testattiin SRS-30 kyselyn rinnalla potilasjoukossa jonka ryhtihäiriöiden määrää ja vaikutusta arvioitiin osatyössä III. Keski-Suomen keskussairaalassa 2007-2016 leikattujen 79 selän ryhtihäiriöpotilaan kliininen ja kuvantamistulos, potilastyytyväisyys ja huonoa tulosta ennustavat tekijät analysoitiin osatyössä IV.

Tulokset

Sagittaalisten lantio-rankamuuttujien mittausten luotettavuus ja toistettavuus osoittautui hyväksi (toistettavuuskertoimet ICC 0.78-0.99, mittauksen keskivirhe SEM

0.80-6.2° tai 2.2-5.8 mm välillä). Mittaajan kokemus vähensi ja lukuisat, vaikeasti tunnistettavat maamerkit röntgenkuvassa lisäsivät mittausten välistä virhettä.

Suomenkielisen SRS-30 kyselyn toistettavuus ja sisäinen yhtenevyys olivat hyvät (ICC 0.905, SEM 0.17, Cronbach α 0.885). SRS-30 oli pätevä erottelemaan kipua, minäkuvaa ja tyytyväisyyttä hoitoon suhteessa vertailumittareihin. Kohtalaista ja vaikeaa ryhtihäiriötä sairastavien SRS-30 toimintakyky (p=0.022) ja minäkuvaosioiden (p=0.016) välillä oli tilastollisesti merkitsevä ero.

Perättäisessä valikoimattomassa 637 aikuispotilaan tutkimusjoukossa 25 %:lla oli kohtalainen ja 11%:lla vaikea selän ryhtihäiriö. Vaikeaa ryhtihäiriötä sairastavat olivat vanhempia, lihavampia ja vähemmän fyysisesti aktiivisia kuin muu tutkimusjoukko. Kolmiportainen SRS-Schwab-ryhtivirheluokitus erotteli hyvin potilaat ryhtihäiriön vaikeuden ja siihen liittyvän SRS-30 elämänlaatumittarin toimintakyvyn (p=0.004) ja minäkuvan (p=0.030) sekä Oswestryn toimintakymittarin tulosten (p=0.033) mukaan.

Ryhtihäiriön leikkaushoito paransi merkitsevästi (p=0.001) toimintakykyä Oswestryn toimintakykymittarilla sekä vähensi selkä- ja alarajakipua kipujanalla mitattuna. Radiologiset lantio-selkämuuttujat paranivat leikkauksella merkitsevästi ja ero säilyi 4-5 vuoden seurannassa (p≤0.001). Luun tai instrumentaation pettäminen johti 13.9% uusintaleikkausriskiin ensimmäisenä leikkauksen jälkeisenä vuotena ja 29.8% riskiin viiden vuoden seurannassa. SRS-30 kysymysten perusteella 49(62%) potilaista oli tyytyväisiä leikkaukseen ja 57(72%) tulisi samassa tilanteessa leikkaukseen uudelleen. Depressio ennusti huonoa leikkaustulosta riskisuhteella 6.97(p=0.018).

Johtopäätökset

Tutkimusjoukko koostui perättäisistä, valikoimattomista aikuispotilaista, joilla oli pitkittynyt rappeutuman aiheuttama selkäsairaus ja tulos on siten yleistettävissä. Röntgenkuvan lukijan kokemus parantaa hyvää lantio-selkämuuttujien mittauksen luotettavuutta ja toistettavuutta erityisesti tarkasteltaessa useita ja vaikeasti määritettäviä maamerkkejä. Suomenkielinen SRS-30 kysely osoittautui luotettavaksi ja toistettavaksi tutkimusjoukossa. Kolmiportainen SRS-Schwab ryhtihäiriöluokitus erotteli hyvin ryhtivirheiden vaikeusasteet ja niihin liittyvän terveyshaitan. Pitkän ajan seurannassa radiologinen ja kliininen ryhtihäiriön leikkaustulos säilyi merkitsevästi lähtötilannetta parempana. Uusintaleikkauksen riski oli suurin ensimmäisen leikkauksenjälkeisen vuoden aikana. Kuitenkin suurin osa potilaista oli tyytyväisiä leikkaustulokseen komplikaatioista huolimatta. Masennus ennusti huonoa elämänlaatumittaritulosta ryhtihäiriöleikkauksen jälkeen.

Avainsanat: aikuisen selän ryhtihäiriö, skolioosi, kyfoosi, koko rangan röntgenkuva, toistettavuus, luotettavuus, pätevyys, validointi, tulosmittari, toimintakyky, Scoliosis Research Society, SRS-30, SRS-Schwab luokitus, selkäkirurgia, lantion kiintokulma, lantion kallistuskulma, sagittaalinen pystyakseli, lannelordoosi

1 INTRODUCTION

Back pain originating from multiple spinal disorders is the leading cause of disability worldwide. Almost all people suffer from back pain during their lives. While fractures, infections and tumours are specific mechanisms for back pain but it is not possible in many cases to identify a single specific cause of back pain (Hartvigsen et al. 2018). Back pain has frequently been explained as resulting from degenerative changes that develop over the years and can be detected with imaging. The underlying medicinal pathologies are highly complex, and confounding variables like physical and mental co-morbidity, smoking, obesity and excessive physical requirements increase the risk for back and leg pain. The correlation between clinical symptoms and a single radiological imaging method result is poor.

Adult spinal deformity (ASD) is a complex entity comprising multiple anatomical and functional changes and is often associated with decreased health-related quality of life (HRQoL) (Glassman et al. 2005b and Scheer et al. 2018a). ASD may initiate from common and negligible degenerative changes in the intervertebral discs and facet joints and in muscular function (Aebi 2005). In some individuals, spinal degeneration can progress into a severe three-dimensional deformity, which affects spinal alignment and balance, generating severe dysfunction and leading to incapacitating pain.

Interest in the diversity of pathologies and spino-pelvic alignment has increased over the last twenty years. The categorization of normal body and trunk balance (Duval-Beaupère et al. 1987 and 1992, Vialle et al. 2005, Roussouly et al. 2006, LeHuec et al. 2011a and 2011b) and normal alignment of the spine has evolved into clinical guidelines for identifying pathological conditions (Dubousset 1994 and Schwab et al. 2012). The decision on optimal individual treatment is a multidisciplinary process. Patient-reported outcome measures (PROM) are an important tool in detecting the problems caused by a musculoskeletal structural disorder. The Scoliosis Research Society (SRS) has developed instruments to measure HRQoL in cases of spinal deformity. Initially, questionnaires were introduced for adolescent idiopathic scoliosis and these were later adapted for clinical use in adult patients. The SRS Questionnaire version 30 contains additional questions for post-surgical patients, including questions on self-image and satisfaction with management. To increase comparability between studies and treatments, the Oswestry Disability Index (Fairbank and Pynsent 2000 and Pekkanen et al. 2011) and the visual analogue scales (VAS) (Price et al 1983) for leg and back pain have been included. To characterise the study population in greater detail, general health instruments such as the Short-Form-36/RAND-36

(Hays and Morales 2001) and depression scale (DEPS)(Poutanen et al. 2010) are used to screen for the confounding aetiologies of pain and disability.

A spinal deformity or malalignment detected in imaging is not an autonomous indication for surgery. No evidence-based physical rehabilitation or medication protocols exist for severe deformities (Smith et al. 2016 and Scheer et al. 2018a). Conservative treatment is the preferred option providing it is effective, or the patient is deemed inoperable, because deformity surgery is costly, includes risk for complications and reoperations and results in a stiff, fused spine.

In the surgical correction of adult spinal deformity it its crucial to ensure proper sagittal alignment, to centralize the head over the pelvis and to restore a horizontal gaze. This provides spinal deformity patients with a more ergonomic standing and gait position and alleviates the painful and exhausting muscular distress, which has compensated for the rigid deformity with the dynamic parts of the skeleton (Le Huec et al. 2015b and Schwab et al 2010). Correction can be achieved with a wedged osteotomy or by multiple segmental procedures either to the posterior or anterior column of the spine combined with spinal fusion.

This research was initiated to study the prevalence and clinical relevance of different grades of spinal deformities in a consecutive patient cohort with prolonged spinal disorders of degenerative origin. An important aim was to study and validate the crucial valuation instruments. Specifically, the reliability and repeatability of measurements taken from full spine radiographs was evaluated. The SRS-30 questionnaire was linguistically and culturally adapted and validated for clinical use among Finnish spinal disorder patients. The final aim was to analyse radiographic and patient-reported outcomes after spinal deformity surgery in our own institution utilising the results of Studies I and II.

2 REVIEW OF THE LITERATURE

2.1 Adult spinal deformity

Adult spinal deformity (ASD) is defined as a three-dimensional scoliotic, sagittal, kyphotic, spondylolisthetic or rotatory deformity of the spine (York and Kim 2017) due to multiple aetiologies (Aebi 2005). The deformation can occur simultaneously in the coronal, sagittal and axial planes (Ames et al. 2016) of the body (**Figure 1**). The sagittal balance of the body is composed of individual radiographic alignment of the spine and pelvis, visual, vestibular and muscular function and general health of the patient (Aartolahti et al. 2013, Diebo et al. 2015b).

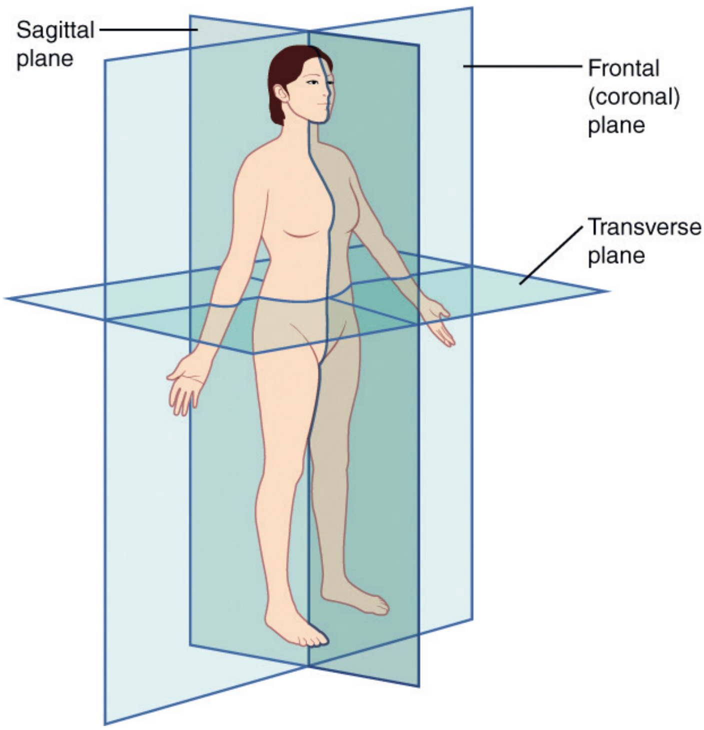


Figure 1. Anatomical planes of the human body. From: https://commons.wikimedia.org/wiki/File:Planes_of_Body.jpg

2.2 Epidemiology and economy

With rising life expectancy and a growing elderly population, it is predicted that an increasing amount of symptomatic adult spinal deformity (ASD) patients will need surgical treatment (Fehlings et al. 2015). Schwab et al. (2005a) reported a prevalence of adult scoliosis, i.e. coronal deformity only, of up to 68% in an elderly volunteer population aged 60-90 years. The prevalence of all forms of adult spinal deformity is not known due to the complexity of the disease. However, the prevalence of clinically significant ASD can be estimated indirectly from the statistics for deformity surgery. Within the past ten years in the United States, the number of ASD operations has shown a 2.5-fold increase (Faraj et al. 2017) without any increase in adolescent operations (Ames et al. 2016). The volume of spinal fusions, including ASD patients, increased by 62.3% in the USA between 2004 and 2015 (Martin et al. 2018). Spinal sagittal imbalance causes significant disability and loss of health-related quality of life equal to those caused by cancer, diabetes and heart diseases (Pellise et al. 2015, Bess et al. 2016). Spinal deformity surgery is associated not only with high costs, complications and reoperations but, depending on patient selection and type of surgery, also with good HRQoL (Fischer et al. 2014, Scheer et al. 2018a). In Finland, which has one of the fastest ageing European populations, the management of ASD patients may be even more demanding in the future. The ASD patient age group 50-70 years was the largest in Finland in 2017 (**Figure 2**) and within the next 10-20 years will be the cohort potentially suffering from significant spinal degenerative diseases requiring surgical treatment. The proportion of persons aged over 65 in the Finnish population is estimated to rise from 17% in 2009 to 27 % by 2040 and to 29 % by 2060 (Statistics Finland (Tilastokeskus), 2009). The prevalence or incidence of ASD in the Finnish population has not been studied.

2.3 Aetiology

ASD is a combination of various spinal alterations (Aebi 2005). Initial degenerative changes affect the intervertebral discs and facet joints. Asymmetrical degeneration can result in scoliotic or kyphotic deformation without former congenital or adolescent deformities. Central or lateral spinal stenosis can occur along with the same degenerative changes. Adolescent idiopathic scoliosis (AIS) can progress to secondary degeneration or malalignment-related imbalance in adulthood. AIS is not the main aetiology for ASD even if, with an overall prevalence of 0.47–5.2 %, it is relatively common (Konieczny et al. 2013). Spinal trauma, infection or tumour may also generate ASD. Extra-spinal pathology can also cause spinal deformation. Oblique pelvis, trauma or disease of the lower limbs leading to leg length mismatch, vertebral anomalies, neuromuscular diseases (e.g. Parkinson's disease) can lead to flexible decompensation of the spine predisposing to a fixed deformity (**Figure 3**). Flat-back deformity or kyphosis after failed lumbar fusion surgery (Eskilsson et al. 2017) can cause sagittal malalignment and constitutes the iatrogenic aetiology for ASD. Aging decreases the sagittal balance of the trunk (Mendoza-Lattes et al. 2010). Not all sagittal deformities are automatically related to the natural course of the aging spine but are separate degenerative diseases and targets for specific treatment (Gelb et al. 1995).

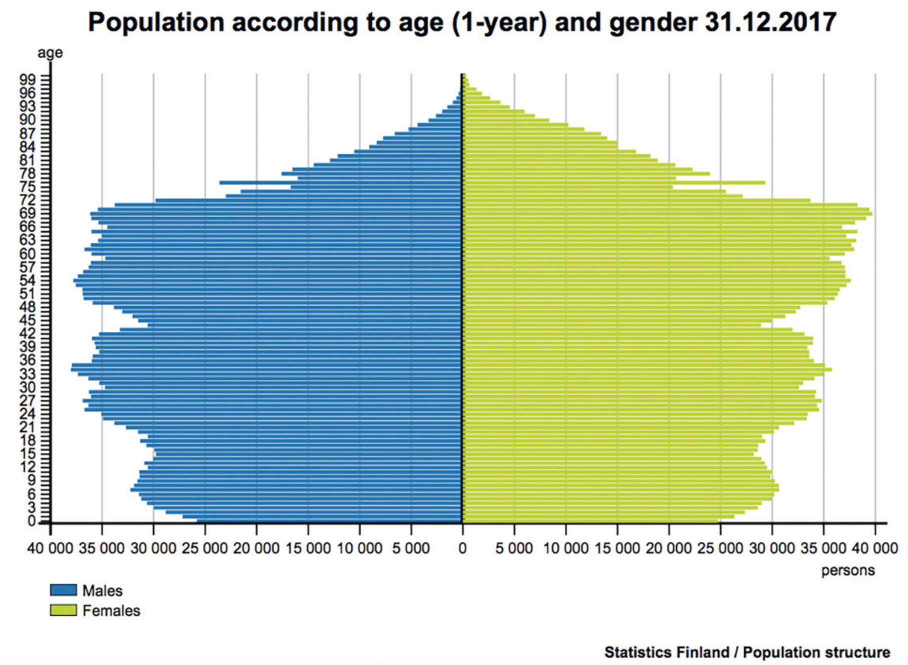


Figure 2. Age structure of the Finnish population in 2017. Reproduced with permission of Statistics Finland (Tilastokeskus).

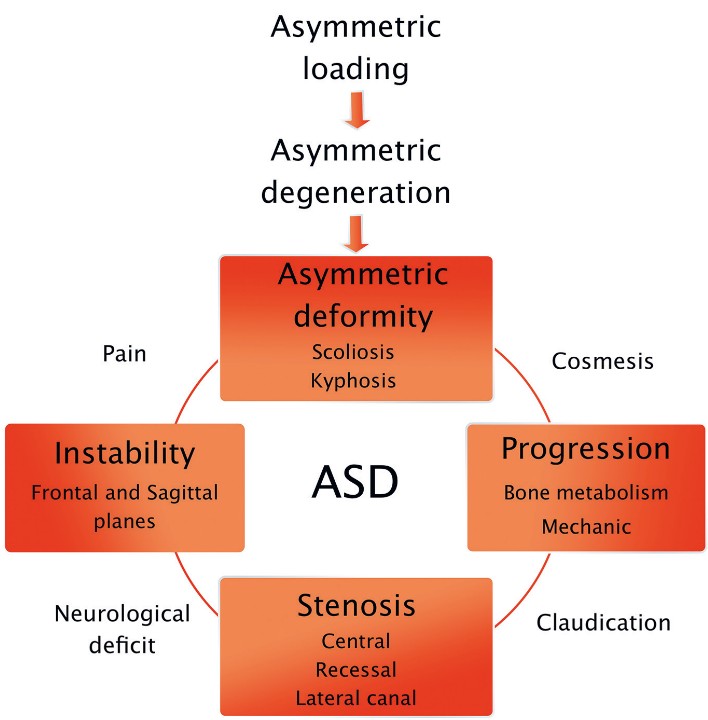


Figure 3. Pathophysiology of adult spinal deformity (ASD). Data adopted and modified from Aebi (2005).

2.4 Imaging

2.4.1 Development of spinal deformity imaging

In the 1920s, the first clinical radiographs of the spine were used to detect fractures or foreign bodies after perforating trauma (Hoeffner et al. 2012). The new method of imaging the spine with radiographs also inspired the new profession of chiropractors, who were distinctly separated from the medical profession. The first full spine anterior-posterior (AP) radiograph was achieved by W.L.Saussa in 1923 to practise chiropractors' non-scientific theory of the benefits of spinal manipulation in joint dysfunction and subluxation for general health (Henderson 1980).

Imaging techniques were further developed in the 1940s, when the importance of patient positioning was recognized (Cameron 1947). The aim of imaging remained one of diagnosing changes in the neural or skeletal soft tissues that affect the bony spine. In the 1950s, the imaging of intervertebral discs pointed the way to a more spine-specific use of imaging. Imaging of spinal deformities for therapeutic purposes started in the early 1950s with the diagnostics of Pott's disease in the tuberculotic spine (Perroy and Mestre 1954). The imaging of other aetiologies for scoliosis or kyphosis started to develop at the same time (Shorkey and DeAngelis 1951). In the same era, in 1953 Paul Harrington developed the first surgical implants designed to correct spinal deformity (Harrington 1963).

Imaging of the full spine expanded in the 1970s and 1980s along with increasing interest in posture and symptoms related to spinal imbalance. Fear of high doses of radiation (Bhatnagar et al. 1981) limited the medical use of full spine imaging and the liberal use of x-rays by chiropractors was disapproved.

Valid indications for full spine radiographs were severe scoliotic or kyphotic deformations the treatment of which was guided by imaging of the whole spine in the standing position. In 1972, Jean Dubousset introduced the concepts of "pelvic vertebra" (**Figure 4**) and the cone of economy, indicating the complex radiographic three-dimensional character of spinal deformity (Dubousset 1994).

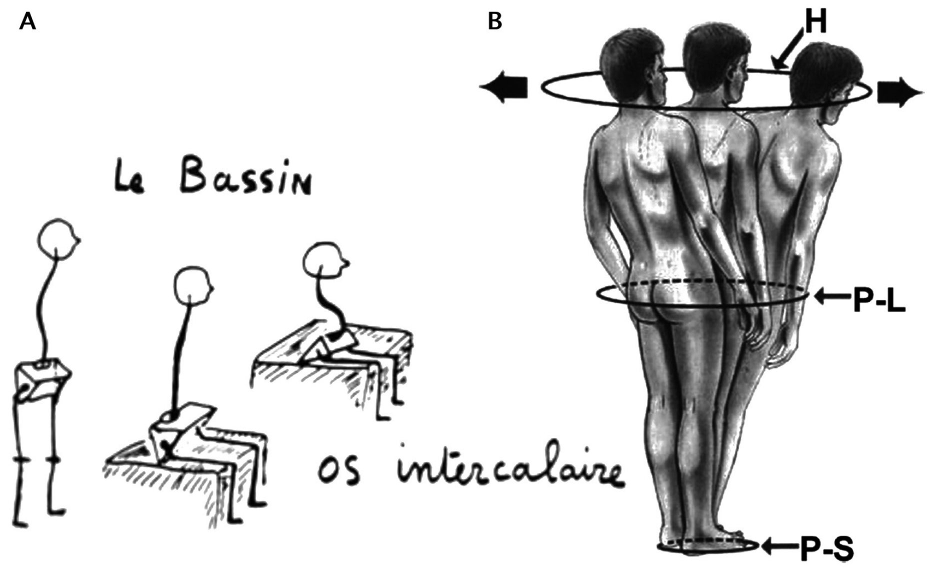


Figure 4. Drawings by Jean Dubousset sketching the functional relationship of the spine and pelvis (A) and the concept of the cone of economy to maintain balanced erect position (B). Deviation from the centre within the zone results in greater muscular effort and energy expenditure to maintain an upright posture. Deviation of the body outside the cone results in falling or requiring support. (© 2010 From Applications in spinal imbalance by Husson et al. Reproduced by permission of Elsevier Masson (A) and © 2010 from Adult spinal deformity-postoperative standing imbalance: How much can you tolerate? An overview of key parameters in assessing alignment and planning corrective surgery by Schwab et al. Reproduced by permission of Wolters Kluwer (B).)

In the 1990s, Ginette Duval-Beaupère and her study group collected the previous data on the impact of trunk position on patient symptoms. The full spine radiograph was the basic tool used in creating the very first clinically important spinopelvic landmarks, including the concepts of the sacral slope and pelvic incidence (Duval-Beaupère et al.1992). The quality of full spine images has since improved, and the technical development of imaging has decreased the amount of radiation to which patients were exposed **(Figure 5).** The next level of full spine imaging was introduced in France in 2002. The EOS (Biospace Imaging, Paris, France) imaging device generates a radiographic full-body image, which enables 3-D measurements and reconstruction (Dubousset et al. 2005). It has a lower radiation dose area product level than traditional computerised tomography and it enables imaging the patient in the standing position.

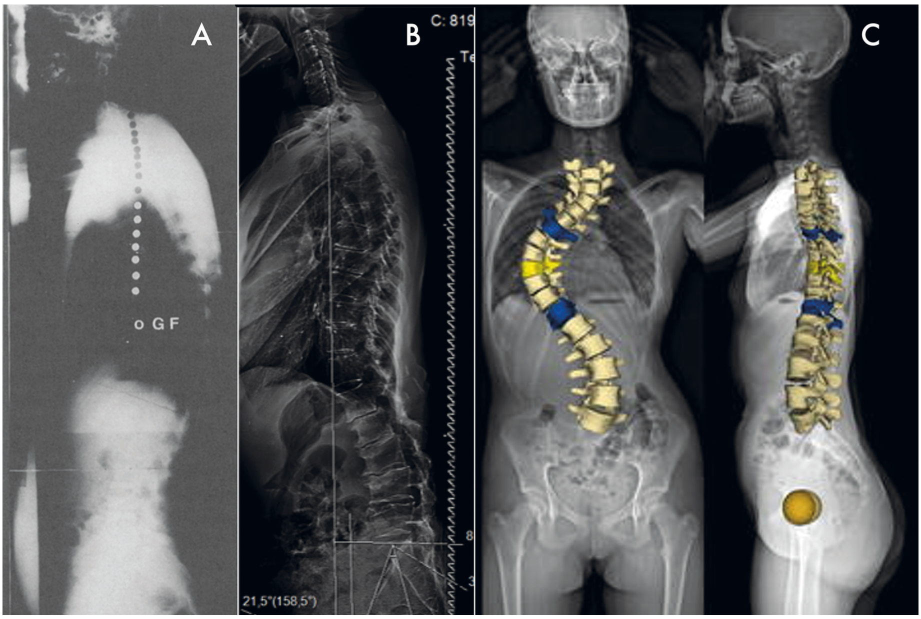


Figure 5. Image quality and resolution of landmarks in full spine radiographs from different decades: late 1980's analogue, present digital and EOS images. (Figure 4A © 1992 From A barycentremetric study of the sagittal shape of spine and pelvis: The conditions required for an economic standing position by Duval-Beaupère et al. and Figure 4C © 2012 From The EOS™ imaging system and its uses in daily orthopaedic practice by Illés et al. Both reproduced by permission of Springer Nature.)

The first full spine AP view radiograph was produced in 1923 on 14 x 36 inch (36 x 91 cm) film (Henderson 1980). Later, the PA scoliosis or the AP and lateral view full spine radiographs were obtained on a single 90 x 30 cm or 60 × 30 cm film cassette. Currently, the traditional x-ray film has been replaced with digital image capture devices. The digital detector panels can be either indirect panels, which require optical reading before the image is visual, or direct panels, where x-rays are converted directly to electrical signals which can be displayed as an image on a monitor. The digital x-ray methods have reduced the dose area product and improved image quality markedly compared to conventional film radiographs (Kluba et al. 2006).

At present the digital full spine standing radiograph is produced from two to three sub-exposures depending on the subject's height. Digital sub-images are processed and aligned automatically into a single composite image using the overlapping anatomical content of the sub-images. A radiographer inspects the composite image visually and misaligned images are re-aligned manually. The imaging device's radiation (mAs) adjustments are based on patients' diameter, constitution, and presumed bone density, according to a 4-class scale (lean, normal, large, or obese), in the imaging area size.

2.4.2 Patient positioning

The standing position is crucial for the validity of full spine imaging. The patient should be able to stand still during the imaging procedure, which may last up to 10 to 20 minutes depending on the patient's body composition and co-operativeness. In both views PA and lateral, the patient stands with the feet 10-12 cm apart. The spine is placed as close to the detector as possible to diminish magnification bias. Hips and knees are extended in a neutral position to avoid bias from compensation for the deformity. Tyrakowski et al. (2014) found that >30° malrotation of the pelvis compared to front line measurement of the pelvic parameters is not reliable. As the measurement of pelvic incidence (PI) from radiographs is the baseline for every surgical planning (LeHuec et al. 2011a), the placing of the pelvis parallel to the front line is essential. The position of the upper arms affects the sagittal shift of the trunk. The natural standing position with arms hanging relaxed beside the body is the optimal position, but due to superimposition of the arms and spine the arms must be elevated. Fists held in the ipsilateral clavicles position is frequently used (Aota et al. 2009). Marks et al. (2009) compared imaging positions and found that all the reported methods caused negative shift of the sagittal vertical axis (SVA) while Legaye and Duval-Beaupère (2017) found a shift from the gravity line dependent on arm position. Passive 30° flexion of the shoulders was closest to the neutral standing position in both the latter studies. The patient must not lean on anything or actively support the upper extremities (**Figure 6**).

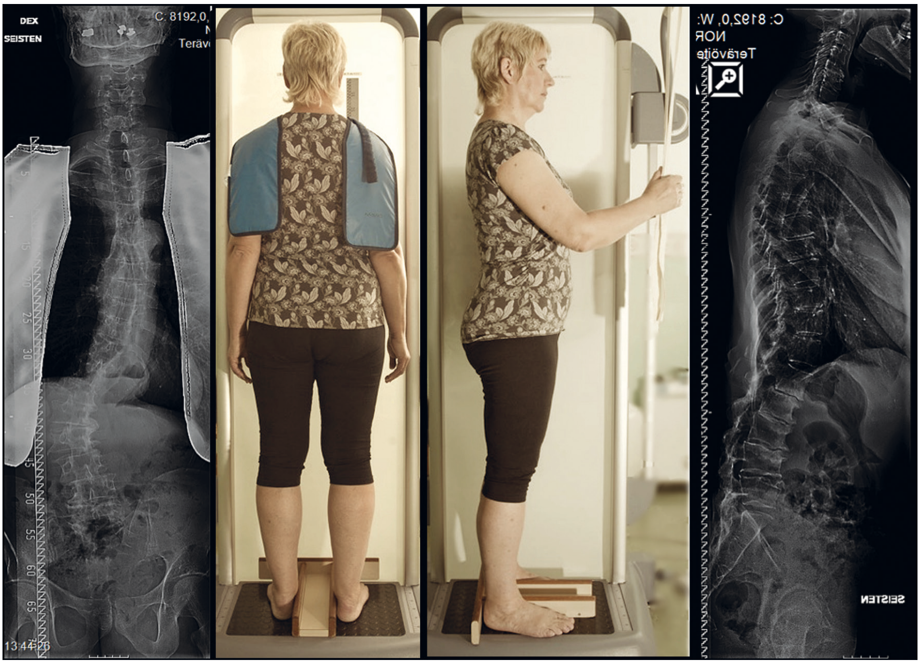


Figure 6. Patient positioning for PA and lateral view full spine radiographs (centre). Reproduced by courtesy of Eero Kauppinen and Maija Pellinen, Department of Imaging, Central Hospital of Central Finland. Composite full spine radiographs in frontal (ap/pa) and lateral views (left and right). The jigsaw line is for manual matching of the subimages.

2.4.3 Bending x-rays

To explore the rigidity of spinal curves or the instability of a segment, bending x-rays are obtained. Coronal plane bending and imaging can be performed in an upright (sitting or standing), supine, or prone position (Vendatam et al. 2000, Bekki et al. 2018). Coronal and kyphotic curves can also be bent with a fulcrum in the lateral decubitus (**Figure 7**) or supine position (Li et al. 2011, Cheung et al. 2010).

All the above models for predicting fusion levels are studied in adolescent patients with relatively flexible coronal curves. The optimal bending positions for imaging are also more suitable for children and adolescents with flexible spines than adults with spinal deformity. The interpretation of adult lateral bending images is derived from adolescent models and their usefulness for surgical planning is dependent on the surgeon's experience.

Imaging segmental instability with flexion-extension radiographs is a somewhat controversial but frequently used method when planning spinal fusion surgery. Asymptomatic individuals can have translational motion in lumbar segments of 3-4mm or greater, a situation regarded in many studies as pathological (Hayes et al. 1989). To substantiate translational movement of the spine in lateral view radiographs, the bending technique must focus the maximal torque on the examined area, typically the lumbar spine (Wood et al. 1994). The utility of flexion-extension radiographs has been questioned in several studies (Liu et al. 2015, Pieper et al. 2014) as the same information is obtainable from upright spine radiographs and supine MRI images without exposing the patient to additional irradiation.

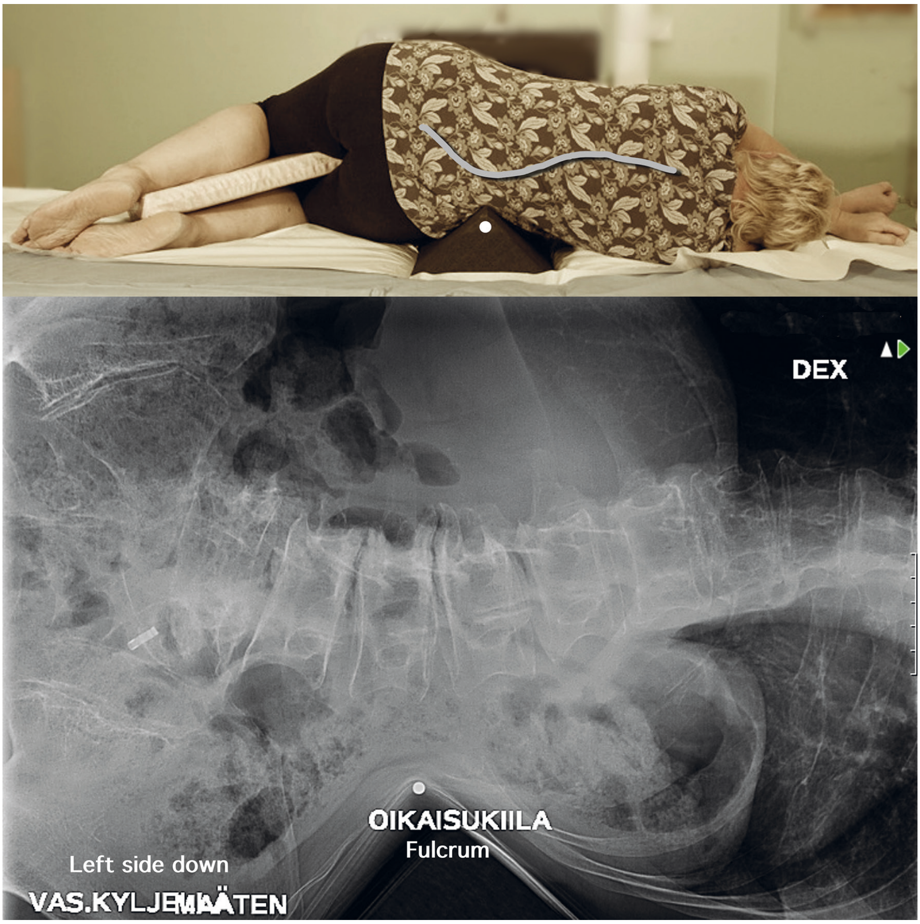


Figure 7. The radiolucent fulcrum with a radiopaque marker at the top is placed at the apex of the scoliotic or kyphotic curve. Curves are identified from full spine radiographs or palpable deformities. Reproduced by courtesy of Eero Kauppinen and Maija Pellinen, Department of Imaging, Central Hospital of Central Finland.

2.4.4 Digital measuring tools

Anatomical landmarks and lines were drawn with a pen and measured with an angular ruler in the era of film radiographs. The digital picture archiving and communication system (PACS) includes the software for pinpointing landmarks, measuring angles and distances. Distance measurements are based on imager pixel spacing, where all distance measurements are physical distances measured at the front plane of the detector housing. Without calibration the distances are comparable only with measurements achieved from similar settings. Angular measurements are not vulnerable to magnification error; however, if the imaging protocol is not standardised and patient positioning fails, the interpretation of the angular measures can fail (**Figure 8**). Good image quality helps in identifying anatomical landmarks; these must be manually identified even when using sophisticated semiautomatic measurement and planning software such as Surgimap (Surgimap Spine, Nemaris Inc, New York, NY, USA). The use of a semiautomatic computerized measurement method diminishes the variation between measurements and measurers (Gupta et al. 2016) and eliminates differences between raters (Lafage et al. 2015).

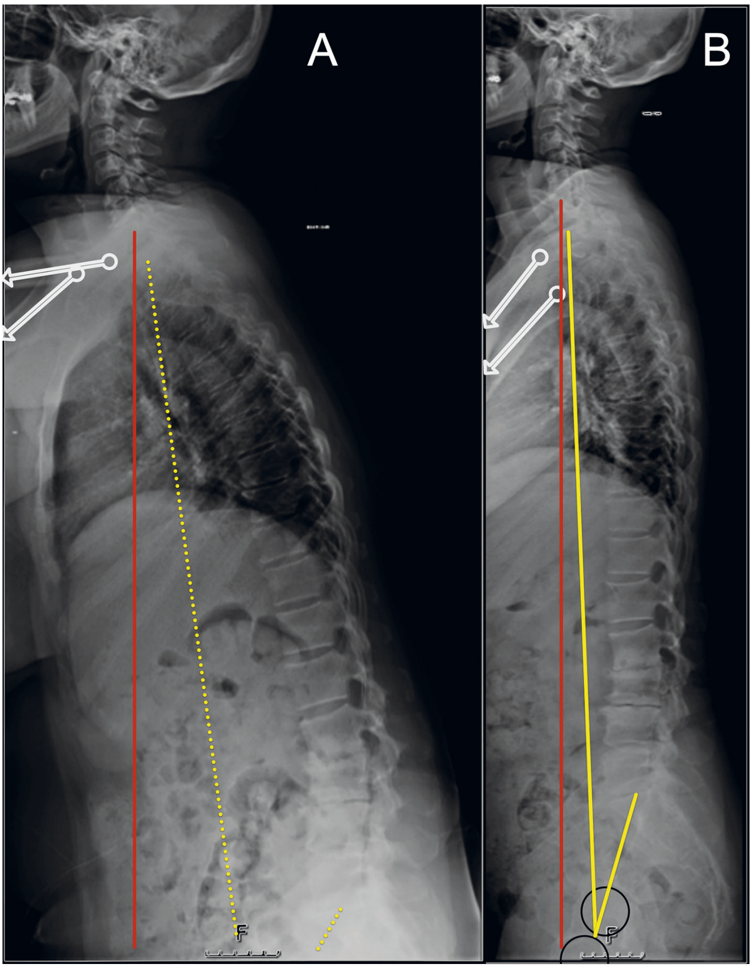


Figure 8. Full spine radiograph lateral view of the same patient within a day's interval. The effect of failed patient positioning and image cropping (A). Red line: sagittal vertical axis (SVA), yellow line: T1 pelvic angle (TPA). Femoral heads and spinopelvic landmarks.

2.5 Sagittal balance, alignment and spinopelvic parameters

2.5.1 Evolution of the sagittal alignment of the human spine

The evolution of spinal sagittal balance possibly began in early hominids 5-6 million years ago. The first evidence of a bipedal and upright position in human ancestors was found when the anatomist and controversial scientist Raymond Dart received the fossil skull of the subsequently termed hominid Australopithecus Africanus (Dart 1925), dated as living 2-3 million years ago. Homo Erectus appeared 1.8 million years ago and was taller and more adapted to an erect bipedal posture than the australopiths. The development of an erect posture and bipedal gait required shortening, verticalising and widening of the pelvis (Le Huec et al. 2011a, Gruss and Schmitt 2015) (**Figure 9**).

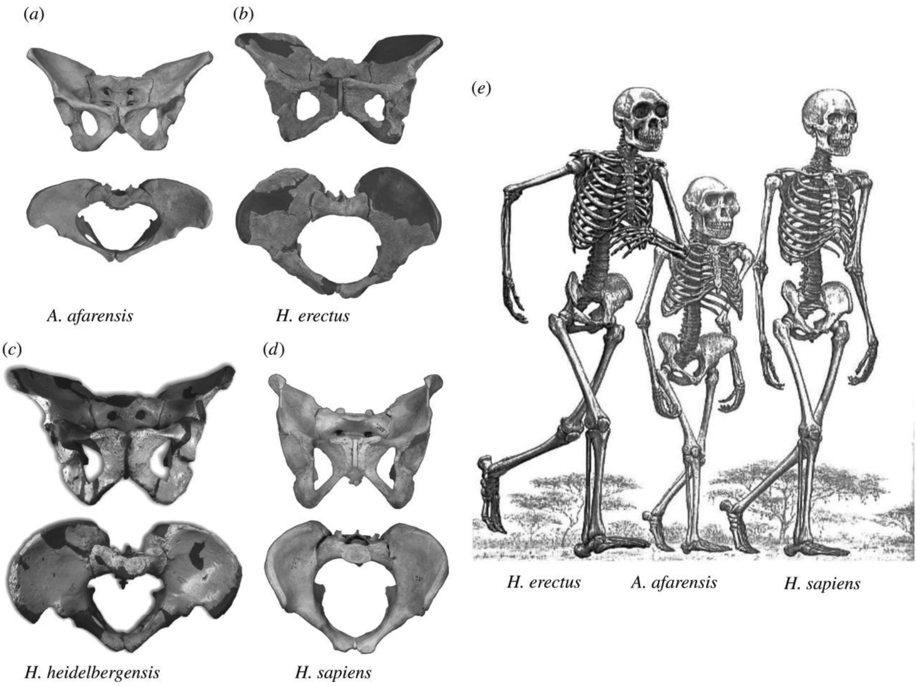


Figure 9. Evolution of pelvis and hominid upright posture from female Australopithecus afarensis to Homo sapiens. (© 2015 From The evolution of the human pelvis: changing adaptations to bipedalism, obstetrics and thermoregulation by Gruss and Schmitt. Reproduced with permission from The Royal Society, Phil. Trans. R. Soc. B.)

Lumbar lordosis (LL) developed later than the curve-shaped thoracolumbar spine, as LL creates the posterior shift of the centre of gravity and enables efficient erect bipedalism (Haeusler et al. 2002). LL eliminates the hip joint torque induced by gravity in the bipedal stance and walking gait (Latimer and Ward 1993, Whitcome 2012). The flexible s-shaped spine also allowed balancing of the spine during running and walking (Schmitt. 2003).

The development of lumbar lordosis and the s-shaped spine is hypothesized to be a reactive change related to the Euler column compression theory, which measures the load a column can bear while remaining straight. Elasticity, unsupported length and relative intensity per loaded area of a column have an influence on the critical load after which the column begins to bend (Gibson and Ashby 1997). In the c-shaped spine of the pre-hominids, the center of gravity was far to the front of the pelvis, hips and feet (Whitcome 2012). The length of the lumbar spine and the number of lumbar vertebrae were hypothesised to allow bipedalism and the development of LL. In fossil studies it remains controversial whether the original lumbar vertebrae number in hominids and the early Homo genus (e.g. H. erectus) was six or five (Haeusler et al. 2002, Whitcome 2012). The numerical variation in lumbar vertebrae in modern H. sapiens is related to Hox-gene mutations and not derived from the vertebral count of ancestors (Wellik and Capecchi 2003). The change in orientation of the lumbar zygapophyseal joints and the development of larger lumbar vertebrae and musculature required to better carry the body weight in the later Homo genus preceded the biological construct of the Homo sapiens. The modern human spine is a very complex construct enabling mechanical weight bearing, stability and flexibility in the upright position. Unlike any other species, the human hip joints with a high range of motion and the flexible extension-flexion movement of the lumbopelvic structures also allow the sitting position by decreasing LL and markedly increasing pelvic retroversion (Endo et al. 2012) (**Figure 10**) and lumbar lordosis is also unique to humans (Sparrey et al. 2014).

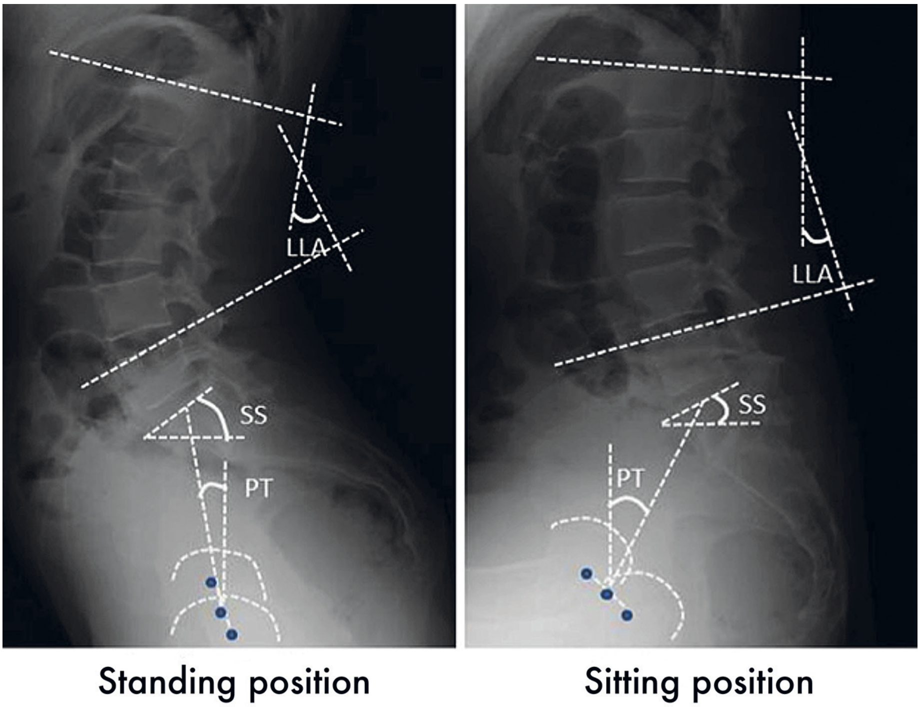


Figure 10. Difference in lumbar and pelvic orientation between standing and sitting positions. (© 2012 From Sagittal lumbar and pelvic alignment in the standing and sitting positions by Endo et al. Reproduced by permission of Elsevier)

2.5.2 Spinopelvic parameters

Coronal plane

John Robert Cobb introduced the Cobb angle as a parameter measured from the spine radiograph (Cobb 1948). It was measured from AP view radiographs identifying the most oblique endplates of the vertebral bodies. Repeated radiographs and measurements gave information about the progress of the scoliotic curve. Eventually, the Cobb angle was adapted for making sagittal measurements of fractures (Keynan et al. 2006), lumbar lordosis and kyphotic deformities (Polly et al. 1996, Kuklo et al. 2001). The measurement of the coronal Cobb angle and sagittal spinopelvic parameters is demonstrated in **Figure 11.**

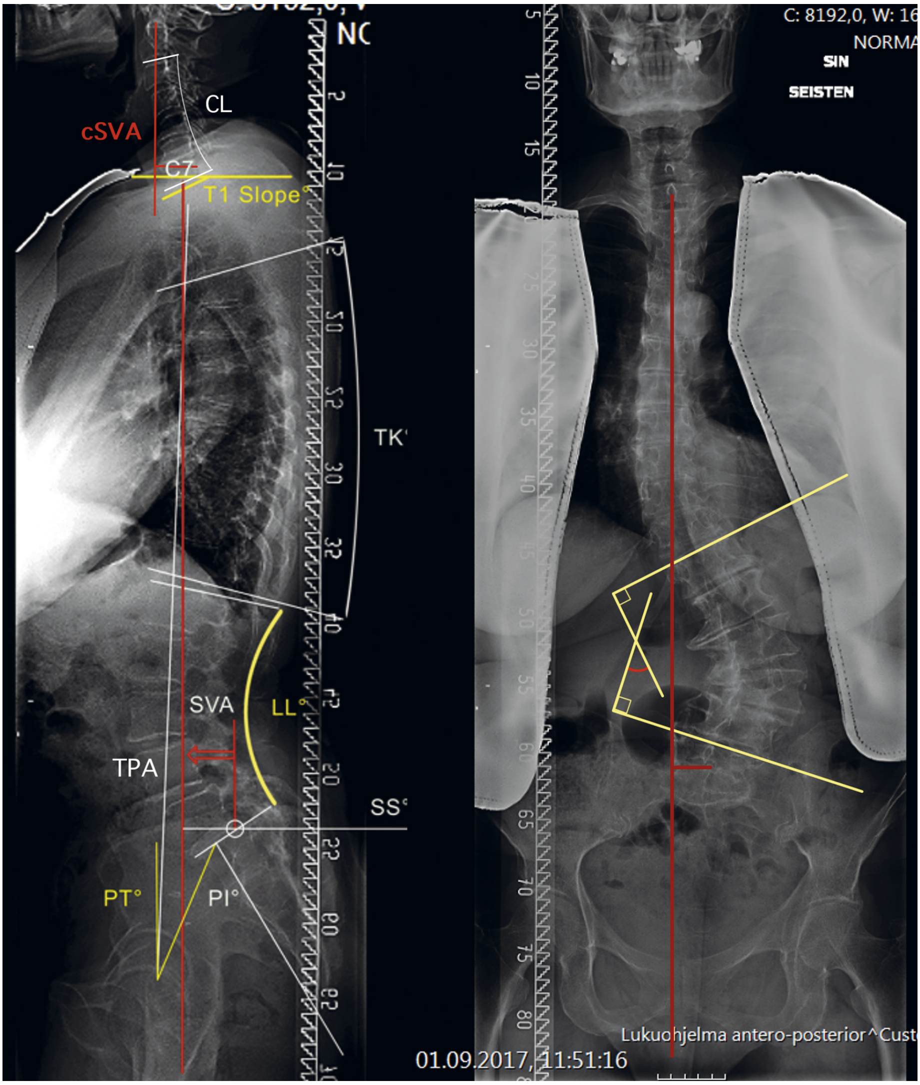


Figure 11. Spinopelvic measurements from sagittal and coronal view radiographs. Left: C7 7th cervical vertebra, CL cervical lordosis, cSVA cervical sagittal vertical axis (C2-C7), TK thoracic kyphosis, TPA T1 pelvic angle, LL lumbar lordosis, SVA sagittal vertical axis (C7-S1), SS sacral slope, PI pelvic incidence, PT pelvic tilt. Right: Cobb angle (yellow), coronal plumbline (red).

Sagittal spine and pelvis

The coalescence of the pelvis and spine enabling the upright position has been an important and interesting topic in research on human evolution and bipedalism. Disability and pain increase when, with changes in spinal alignment, the economical cone of balance line is lost (During et al. 1985). The French surgeon Jean Dubousset made a strong impact on spinal alignment research with his statement that the pelvis is functionally the lowest vertebra (**Figure 4**) and that the position of the pelvis defines the orientation of the spine (Husson et al. 2010).

Among the numerous studies on spinopelvic morphology, the work of Ginette Duval-Beaupère was ground-breaking for the further modern geometric evaluation of the spine and pelvis (Duval-Beaupère and Robain 1987, Duval-Beaupère et al. 1992). The relationship of the vertebrae, sacral endplate, rotational axis of the femoral heads and the centre of weight were analysed from full spine radiographs of young adult volunteers. **Figure 5** demonstrates the development of imaging quality and the resolution of spinopelvic landmarks from the early full spine radiographs to modern digital imaging. 2-dimensional analogue images did not give enough information about the spine and body balance. Gamma-ray scanners and full spine radiographs combined with a computer provided more exact information about biomechanical parameters like body mass and axial load on an individual vertebra (Duval-Beaupère and Robain 1987). The study group of Duval-Beaupère and Robain initiated research on the constant structures of the pelvis from the sacral slope (SS). The authors demonstrated the significance, among the spinopelvic variables, of having a single constant parameter: pelvic incidence (PI). The study resulted in the classical geometric formula: PI = PT + SS (Duval-Beaupère et al. 1992) **(Figure 12**) i.e. pelvic incidende is the sum of pelvic tilt and sacral slope.

Pelvic incidence (PI)

Pelvic incidence (PI) is the angle between the perpendicular line to the sacral upper endplate and its midpoint and the rotational mean centre of the midpoints of the femoral heads. The midpoint of the line between the centres of the femoral heads in lateral view radiographs reliably represents the gravity line of the body in healthy individuals of different ages (Schwab et al. 2006). PI is regarded as a constant morphological parameter that does not change in adulthood. PI renders the concept of normal values problematic, as it is a morphological individual parameter that the other parameters follow. In anatomical studies of healthy individuals, a PI range of 35° to 85° with a mean value of 52°±10° has been found (Vialle et al. 2005). During the growth period, PI is smaller than in adults. In children under 10 years of age, mean PI is 45° and in adolescents over age 10 but under age 18, 49° (Mac-Thiong et al. 2004). However, the sacroiliac joint is not totally rigid, and in young healthy adults a mean change of 3° in PI values was found when the neutral position was compared to anterior or posterior maximal flexion of the pelvis (Place et al. 2017). If 2D instead of 3D full spine radiographs were used, the measurement is liable to measurement error. Furthermore, as the authors state, the 3° difference is not determined, and might not reach the limit of clinical significance.

Legaye et al. (1988) proved the regulatory role of PI in relation to the sagittal curves, especially lumbar lordosis (LL). The fundamental guideline of taking the individual relation of PI and LL into account to ensure a balanced curve after deformity surgery was created after this finding. Thoracic kyphosis (TK) was also found to be proportional to PI in a multivariate regression analysis (Vialle et al. 2005).

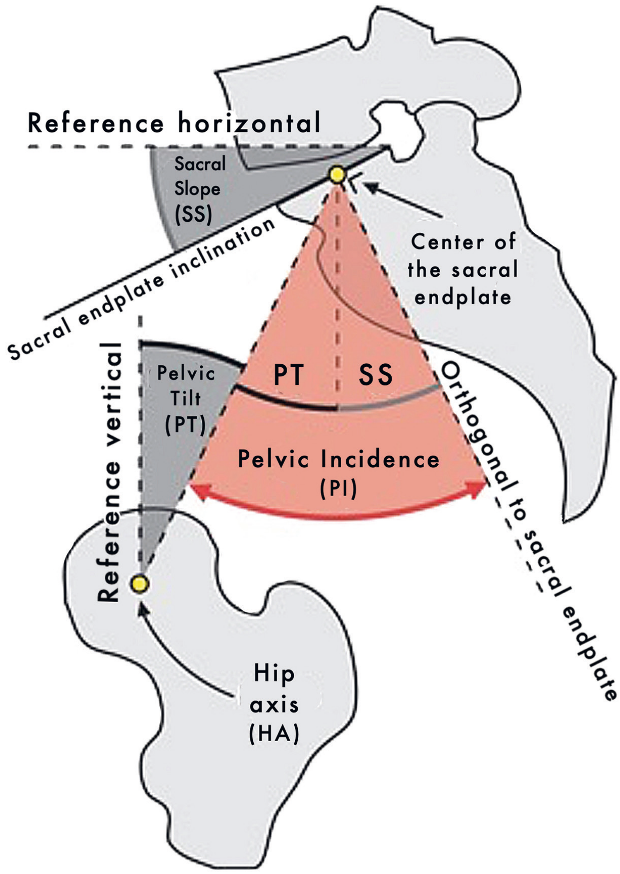


Figure 12. Pelvic parameters in the sagittal plane. Pelvic incidence is independent of the position and orientation of the subject. (© 2012 From Analysis of pelvic incidence from 3-dimensional images of a normal population by Vrtovec et al. Reproduced by permission of Wolters Kluwer.)

Sacral slope (SS)

As PI is a constant angle independent of the rotation of the pelvis, the angle of the sacral slope changes according to the tilting of the pelvis (PT). The slope angle is decreased when the pelvis is rotated into retroversion and inducing an increase in PT and vice versa. Notwithstanding, the SS value does not fall below zero and the maximal pelvic rotation capacity is thus dependent on the steepness of the sacral slope: the higher the slope, the greater the retroversion capacity before SS becomes zero.

The sacral slope is proportional to the overlying LL (Le Huec et al. 2011a). Sacral measurements show the greatest variation of measurement (Aubin et al. 2011). Thus, careful identification of the sacral landmarks and defining the sacral slope are essential to the accuracy of the other angular pelvic measurements.

Pelvic tilt (PT)

With the ability to maintain an upright posture and balanced gait, the Homo genus lost some of the mobility of its ancestors. Pelvic tilt is one of the mobile spinopelvic mechanisms that enable balancing of the upright trunk when the economical cone is endangered. It is thus one of the compensatory mechanisms needed to maintain the sagittal balance of the body. By studying the spinopelvic anatomy of healthy young adults, Vialle and coworkers described the mathematical relationship between PT and PI: PT = -7 + 0.37*PI (Vialle et al. 2015). PT can become negative, i.e. the midpoint of the sacral endplate can rotate anterior to the rotation centre of the femoral heads. The pelvis can rotate posteriorly up to the maximal hyperextension of the hip joints. PT can theoretically maximally increase only a proportion of the SS of an individual's PI (**Figure 12**). Patients with low PI can only compensate for a limited amount of the lost sagittal balance by retroverting the pelvis. Patients with severe sagittal malalignment must deploy other compensation mechanisms to attain a vertical visual line. PT also changes dependent on body position, i.e. whether the subject is standing, supine or sitting (**Figure 4**). PT should be measured from standing radiographs with a standardized imaging protocol.

Spinal deformity and compensation of sagittal malalignment can disturb proper alignment of the acetabular component in hip replacement surgery. Pelvic retroversion can increase the risk of excessive anteversion of the implanted cup (Buckland et al. 2015). This may expose the implant to early mechanical complications, such as aseptic loosening, wear or dislocation (Lazennec et al. 2011, Esposito et al. 2018). The combination of spinal fusion and hip replacement can be problematic, especially among inactive aged persons who may remain sedentary most of the day. The link between a simultaneous decrease in LL and increase in PT in the sitting position (**Figure 10**) will be broken if rigid fusion of the lumbar spine is present. A stiff spine decreases patients' ability to provide additional hip flexion in sitting or hip extension in the supine or standing position. This should be taken into consideration in acetabular cup placement and implant properties to allow good mobility without risk of impingement of the acetabular and femoral components (Lazennec et al. 2011, Phan et al. 2015). It is recommended that the positioning of the cup is templated on a standing radiograph and that the pelvic obliquity, rotation and decreased mobility of the spine are taken into consideration to avoid impingement of the hip joint (Blizzard et al. 2016). Both high and low PI in association with corresponding PT changes might contribute to development of hip osteoarthrosis, but the evidence is controversial. Though, in a recent systematic review Saltychev et al. (2018) found that lower pelvic incidence might be associated with femoroacetabular impingement and with hip problems associated with ankylosing spondylitis due to lower capacity to increase PT.

Lumbar lordosis (LL) and thoracic kyphosis (TK)

Lumbar lordosis in humans is a unique structure among species. LL facilitates many physical functions not only in the vertical but also in the sitting or horizontal positions. In the process of degeneration, the flexibility and alignment of the lumbar spine can change, impacting on symptoms and other spinopelvic parameters. Increased low back pain has a strong relationship with loss of the lumbar curvature (Chun et al. 2017).

The spinal sagittal curves are based on PI. Roussouly and co-workers have described the four types of sagittal curvatures of the spine related to the SS and different angles of the PI (Roussouly et al. 2005, Roussouly and Pinheiro-Franco 2011). Depending on the shape of the curvature, the apex of lordosis is deep-seated in the L4-5 region or higher in L3 region (**Figure 13**). Later a fifth variant with low PI, high apex and anteverted pelvis was added to type 3 curvature by same authors.

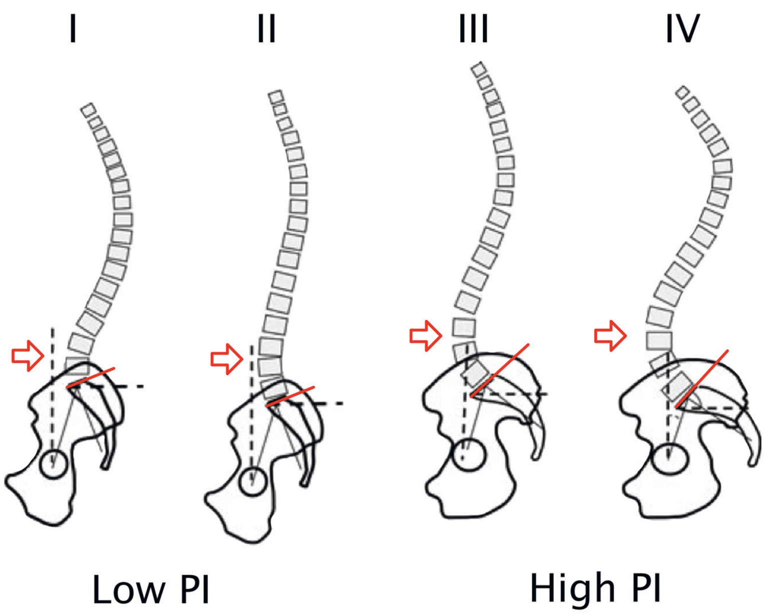


Figure 13. The four curvature types, sacral slopes (red line) and the apex of lordosis (red arrow). (© 2011 From Biomechanical analysis of the spino-pelvic organization and adaptation in pathology by Roussouly and Pinheiro-Franco. Reproduced by permission of Springer Nature.)

The LL curve is elliptical, and the steepest slope is in the lower part of the spine. Barrey and Darnis (2015) have described the proportions of LL in each segment (**Figure 14**). Altogether, 85 % of LL is located between the upper endplates of L3 and S1 and the steepest part, 2/3 of LL, is in the L4-S1 segment. To better predict long-term HRQoL and the outcome and complications of ASD surgery, new PI-based parameters, relative lumbar lordosis (RLL) and a lordosis distribution index (LDI) have been developed (Yilgor et al. 2017b). The RLL is calculated with the formula: LL (L1-S1) minus (0.62 x PI + 29). The LDI algorithm is LL (L4-S1)/ LL (L1-S1) x 100.

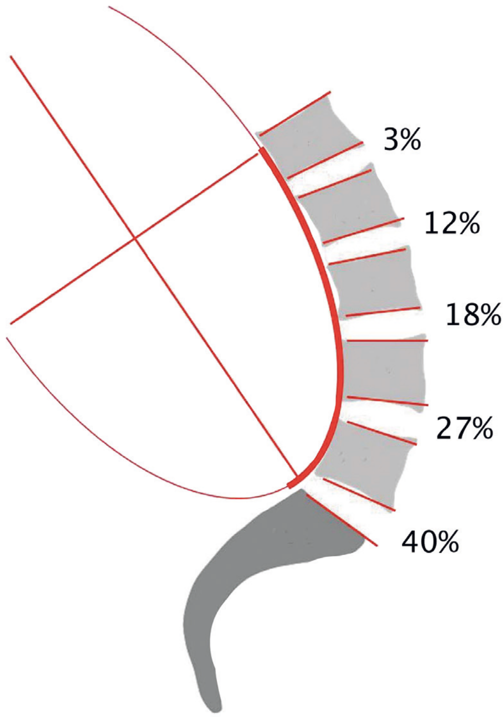


Figure 14. The elliptical shape and segmental proportions of lumbar lordosis. Open Access 2015 From Current strategies for the restoration of adequate lordosis during lumbar fusion by Barrey and Darnis, World J Orthop 2015;18;6(1):117-126 by Baishideng Publishing Group Inc.)

Identification of the optimal individual LL is one of the key issues in planning surgical treatment of the lumbar spine. Failure to restore optimal lordosis while fusing the spine can result in mechanical low back pain, adjacent level degeneration and loss of sagittal alignment, predisposing to activation of symptomatic sagittal balance compensation mechanisms. Schwab et al. (2009) measured LL from full spine radiographs of healthy asymptomatic adults and formulated the equation LL = PI + 9° (±9). In 1989 Bernhard and Bridwell (1989) published their finding that in a balanced spine LL is 10 to 30° larger than TK. After several further studies, applicable formulas without complex measurements were developed for clinical use. Diebo et al. (2015a) published guidelines to restore LL in deformity surgery. For lumbar correction, the simple equation $LL = PI - 10°$ is optimal among patients with high PI and $LL = PI + 10°$ among patients with low PI. In more complex surgery, TK must also be taken into consideration. Rose et al. (2009) published their simple "Kim formula" $PI + LL + TK \leq 45°$, where LL is a negative value, for clinical use. Later Diebo et al. (2015a) published a validated formula $LL = (PI + TK)/2 + 10$ that takes into consideration the clinical outcome and prevention of mechanical complications.

TK can be measured based on several landmarks. The most frequently used is the angle between upper endplate of T4 and lower endplate of T12. To interpret or to compare results, the TK measurement method should be checked as T1-T12 or T2-T12 measurements are also occasionally used. In asymptomatic adults, TK most commonly varies between 34° and 44° but the range varies from 0° to over 70°. It is important to remember that TK is related to the individual's PI and type of sagittal curve of the spine (**Figure 13**) (Boseker et al. 2000, Vialle et al. 2005). The thoracic spine is connected to the rib cage and thus is less mobile than the lumbar or cervical spine. Thus, degeneration is a more infrequent cause of malalignment of TK than of LL. The aetiologies of increased TK are listed in **Table 1**.

Table 1. Different aetiologies of increased spinal kyphosis (Macagno and O'Brien 2006).

Congenital	Defects of segmentation Defects of formation Fixed
Developmental	Scheuermann´s kyphosis Developmental round back Spondylolisthesis
Inflammatory	Infective Pyogenic Tuberculosis
Metabolic	Osteoporosis Osteomalacia
Post-traumatic	Fracture or ligamentous injury
Tumor	Metastatic Neurofibromatosis Other
Chondrodystrophic	Achondroplasia Muchopolysaccharidoses Spondylo-epiphyseal dysplasia
Iatrogenic	Post laminectomy Post irradiation

Cervical alignment

Cervical sagittal alignment is commonly measured as the Cobb angle between the inferior endplates of C2 and C7 (CL) **Figure 11**. The best estimate of cervical lordosis is obtained with the Harrison posterior tangent method. The method requires identification of the posterior walls of all the cervical vertebrae and calculates the sum of the segmental angles (Harrison et al. 2000). This method is useful if semi-automatic measurement software is available but impractical in clinical use if obtained from the radiograph with the basic software tools. Observations of the normative values of cervical lordosis (CL) in healthy subjects vary between 15°± 10° in young adults and 25° ± 16° in individuals over 60 years old (Dubousset et al. 1994, Kuntz et al. 2007 and Iyer et al. 2016). However, several studies have reported kyphotic instead of lordotic sigmoid sagittal cervical alignment in asymptomatic subjects (Yu et al. 2015 and Diebo et al. 2016). Kyphotic normative alignment has also been observed in 13-34% of the cervical spines of asymptomatic individuals (Le Huec et al. 2015a). In their study, Le Huec et al. (2015a) used the C7 slope instead of the frequently used T1slope (TS) to prove that not only is SS predictive of LL but also that the angle of the cervicothoracic junction is predictive of cervical alignment. As CL has large variability, it has been suggested the T1 slope minus CL (TS-CL) parameter is a more reliable measure of cervical malalignment than CL alone. Protopsaltis et al. (2017) proposed that the TS-CL should be less than 20°. Another common measurement of cervical alignment is the C2-C7-sagittal vertical axis (cSVA), which is the distance of the vertical plumbline from the middle of the dens axis from the upper posterior corner of the C7 vertebral body. The normative value defined for cSVA is less than 4cm (Protopsaltis et al. 2017).

Neither the CL, TS-CL nor cSVA normative values take into consideration global alignment or cervical and spinopelvic compensatory mechanisms, such as PT. Thus, two novel parameters, the craniocervical angle (CCA) and C2 pelvic tilt (CPT) to were introduced evaluate cervical malalignment. The CCA is measured as an angle between the lines from the posterior occipital condyle to the posterior part of the hard palate and to the midpoint of the C7 vertebral body (**Figure 15**). This angle takes cervical compensation into account. The CPT angle combines C2 tilt with PT and thus includes the benefits of the TS-CL parameter and removes the effect of lower extremity and pelvic compensation(Protopsaltis et al. 2017). CPT is measured as the angle between the line of the posterior wall of the C2 vertebra and the line that combines the centre of the femoral heads and the midpoint of the sacral endplate. When the CCA decreases, as in the drop-head situation, high ODI and low SRS-22 values are measured. The decrease in the CPT value indicates that the head is aligned above the pelvis and thus the PROM values improve. These measurements require good visibility of the bony structures of the face and skull base in the full spine radiograph and continue to be novel in daily clinical practice. The Chin-Brow Vertical Angle, Slope of Line of Sight, McGregor's Slope and spino-cranial angle (SCA) have also been published as responsive variables in measuring HRQoL (Lafage et al. 2016). McGregor's line runs between the posterior edge of the hard palate and caudal portion of the occipital curve (Figure 15C). Measuring these parameters requires that the cranium is well exposed in the full spine radiograph. In a recent review of the literature, Ling and coauthors concluded that the most important parameters describing cervical sagittal balance are C7 or T1-slope (TS) averaging 20° but not exceeding 40°, cSVA < 40 mm and SCA (83° ± 9°) (Ling et al. 2018). However, despite many research efforts, the role of the cervical spine in relation to the alignment of the different parts of the spine is not yet properly understood.

Global sagittal alignment

The alignment of the spine can be measured with several parameters. They have different properties, which should be known when selecting parameters for clinical use. The parameters presented in this chapter are illustrated in **Figures 11 and 15B.** The sagittal vertical axis (SVA) is the distance of the upper posterior corner of the sacrum from the vertical line running from the midpoint of the C7 vertebral body. The SVA is one of the earliest spinopelvic parameters published (Jackson and McManus 1994). As a distance measurement, it is vulnerable to magnification error of the radiograph. Rotation of pelvis and compensation with flexed knees also influence the SVA. In a comparison between healthy volunteers and patients with low back pain, SVA values below 5 cm were considered normal (Jackson and McManus 1994). Later, Schwab et al. (2012) defined the normal value as below 4 cm in comparison with PROM results.

Spinopelvic inclination was first measured as the angle formed by the T1 (T1SPi) or T9 (T9SPi) vertebral body, centre of the line between femoral head midpoints and the vertical line derived from the measurements of body's centre of mass by Duval-Beaupère (Duval-Beaupère et al. 1992, Lafage et al. 2009) (**Figure 15B)**. These angles are also affected by pelvic rotation and patient position but, as they are angular by nature, they do not present the magnification error risk related to SVA. Average T1 pelvic inclination values of -1.3° ± 3.0° and T9 pelvic angle of 10.5° ± 3.0° have been measured in healthy adult subjects (Vialle et al. 2005).

The most recent measurements of global sagittal alignment, spino-sacral angle (SSA) and T1 pelvic angle (TPA) are not affected by pelvic rotation or patient position during imaging. The SSA is measured as the angle of the sacral endplate line and the line between the midpoints of the C7 vertebral body and the sacral endplate (Roussouly et al. 2006). Roussouly's study group found a mean SSA value of 130°± 8° in asymptomatic adults (Mac-Thiong et al. 2010).

The TPA is the angle between the midpoints of the T1 vertebral body, the femoral heads and the mid-sacral endplate and correlates well with the SVA, PT and PI-LL, which are the sagittal modifiers of the Scoliosis Research Society-Schwab adult deformity classification (Schwab et al. 2012, Protopsaltis et al. 2014). According to the classic work of Vialle et al. (2005), the mean TPA in an asymptomatic population is 12°. When TPA values were reflected on ODI results, the TPA angle of 14° correlated with ODI 20, i.e. minimal disability, and TPA >20° with severe disability, indicating that TPA < 14° is the target value after deformity surgery (Protopsaltis et al. 2014).

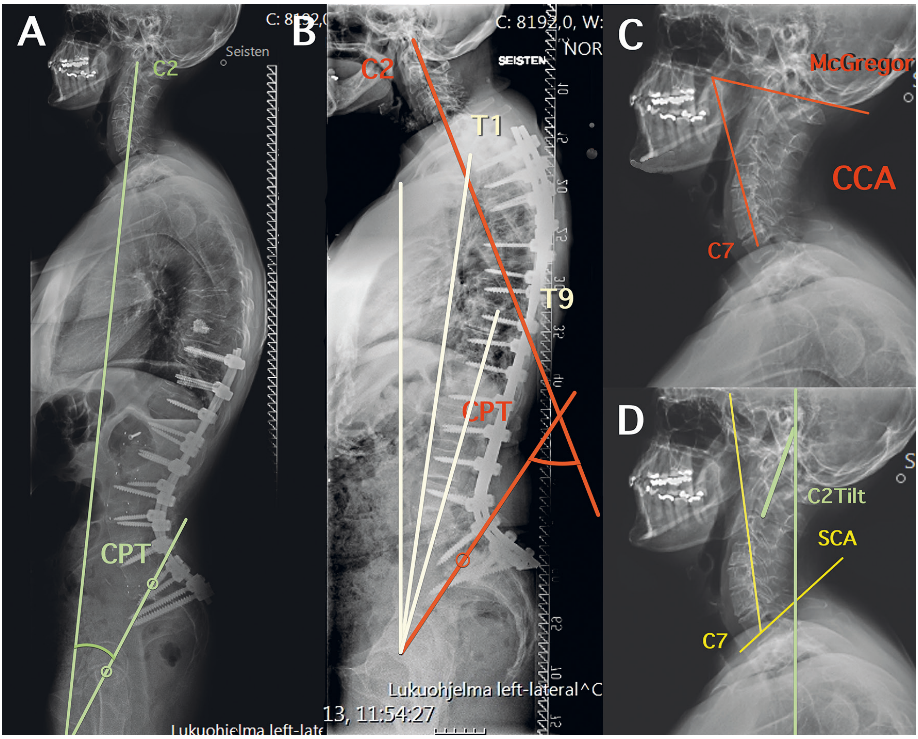


Figure 15. Impact of changes in PT and cervical alignment on the CPT angle. Case A neutral alignment of the cervical spine and low PT. Case B mild drop head and high PT and a higher CPT angle. C: Measurement of craniocervical angle (CCA). D: measurement of C2 tilt and spino-cranial angle (SCA). T1 and T9 spinopelvic inclination (SPi) angles in subimage B.

None of the single parameters of sagittal alignment cover the whole spectrum of PI-related parameters or help prevent the complications related to ASD surgery. Therefore, a new Global Alignment and Proportion (GAP) score has been developed (Yilgor et al. 2017a). The GAP score includes a) the relative pelvic version (the measured minus ideal sacral slope), b) relative lumbar lordosis (the measured minus ideal lumbar lordosis), c) the lordosis distribution index (L4-S1 lordosis divided by L1-S1 lordosis multiplied by 100), d) relative spinopelvic alignment (the measured minus ideal global tilt), and e) an age factor. The practical use of this novel score requires a semiautomatic calculation and surgical planning software. Each parameter receives points from classified threshold values and the total point count indicates either a proportioned or moderately or severely disproportioned spinopelvic state. According to the authors, the GAP score predicts mechanical complications well: the use of GAP decreases the risk for mechanical complications from 47% to 6% by helping to balance the spine proportionally (Yilgor et al. 2017a).

Compensatory mechanisms for sagittal alignment

Compensation for loss of a significant proportion of SS- and PI-related lordosis or an increase in thoracic kyphosis is required for retention of the horizontal gaze. The compensatory mechanisms typically appear adjacent to the problematic anatomical area. When the lower lumbar column is compromised, the upper lumbar and lower thoracic spine may become lordotic or the pelvis retroverted (**Figure 16**). More cranially, the cervical spine is maximally lordosed to compensate for the malalignment. Without sufficient global alignment, the trunk starts to anteriorise (Barrey et al. 2013). Lamartina and Berjano (2014) have described the typical adult deformities and their corresponding compensatory mechanisms (**Table 2**).

A confounding factor in sagittal malalignment is that, to provide more space for the nerve roots, patients with lumbar spinal stenosis tend to lean forward by kyphosing the lumbar segments. If the co-existing sagittal deformation is mild or moderate, patients can forward lean without activating the compensatory PT mechanism. When the global malalignment is worse than indicated by the skeletal deformity and the available compensatory mechanisms are not active, the forward lean is not due to the primary ASD but is an effort to ward off the spinal stenosis. If the spinal stenosis is associated with a severe spinal deformity and malalignment, the compensatory mechanisms are activated earlier, and leaning forward is not used to lessen symptoms from neural compression (Buckland et al. 2016). When the essential feature of human spine, i.e. flexible and functional LL, is lost, the method used by human ancestors to maintain an erect posture, i.e. knee flexion, is deployed. This phenomenon was tested with volunteers who, when asked to walk with minimal sway from the centre of mass of the trunk, adopted deeply flexed lower limbs after the manner of most apes (Schmitt. 2003). If knee flexion is a secondary compensating element for activated maximal PT, gait is a severely impaired shuffle, as the hip extension needed in balanced gait is hindered. The knee flexion angle in upright standing is $< 1°$ in healthy individuals without spinal deformity (Sugama et al. 2011). Thus, the knee angle should be neutralized during the imaging process or counted separately if the imaging position is not controlled for and a full body image obtained. Obeid et al. (2011) found that patients with 10° spontaneous knee flexion lacked at least 30° of lumbar lordosis.

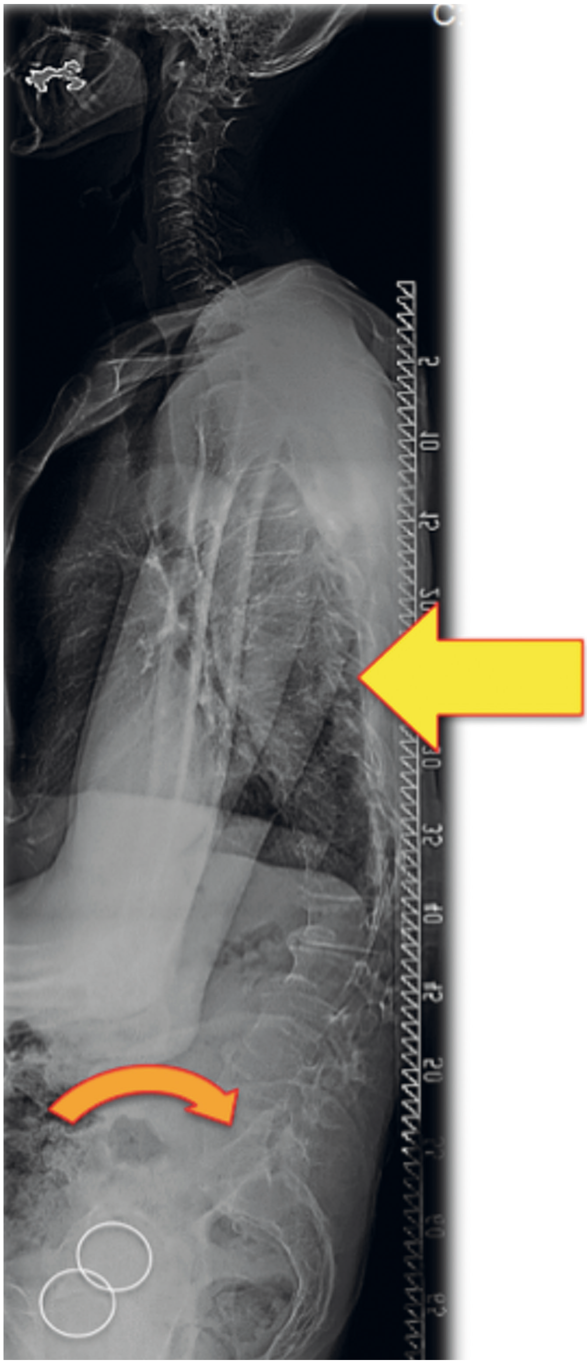


Figure 16. The patient maintains the horizontal gaze by retroverting the pelvis maximally (PT = 45°) and lordosing the flexible thoracic spine (arrows).

Table 2. Compensatory mechanisms for regional spinal deformities. Modified from Lamartina and Berjano (2014).

Deformity patterns	Compensatory mechanism
Normal sagittal alignment	None
Cervical kyphosis	Lumbar hyperlordosis or thoracic lordosis
Thoracic kyphosis	Cervical hyperlordosis Lumbar hyperlordosis
Thoracolumbar kyphosis	Lower lumbar hyperlordosis Pelvic retroversion
Lumbar kyphosis	Thoracic lordosis Pelvic retroversion (flexed knees)
Lower lumbar kyphosis	Upper lumbar hyperlordosis and/or pelvic retroversion
Global kyphosis	Increased pelvic tilt Flexed knees
Pelvic kyphosis	No compensatory mechanisms. Normal pelvic tilt. SVA increased

Spinopelvic parameters and anatomical variants

The normative values of the spinopelvic parameters in healthy asymptomatic subjects are based on studies of patients with total of 24 vertebrae (7 cervical, 12 thoracic and 5 five lumbar vertebrae). Variants in HOX genes can result in four (L4) or six lumbar (L6) vertebrae, which occur in 4-30% of the population (Yokoyama et al. 2016). The L4 and L6 variants belong to the larger group of lumbosacral transitional vertebrae (LSTV). These transitional vertebrae can be mobile or fixed, i.e. to form complete or incomplete fusions of the transverse processes and the pelvis, as described by Castellvi et al. (1984) **Figure 17.** Detecting the transitions is crucial in defining the lowest mobile level of the spine. Among asymptomatic adults with L6 vertebrae and total of 25 vertebrae, the mean values of the spinopelvic parameters were significantly different from those with L5 (Price et al. 2016, Yokoyama et al. 2016). Mean LL was 8°, PT and SS 11° and PI 22° higher than the normative values in the L5 population (Price et al. 2016). In symptomatic adult patients with L6, the PI value was significantly different from that in a comparable L5 population. The parameters that deteriorate with increasing degeneration (PT, TPA, SVA, LL, PI-LL) were not significantly different between the L5 and L6 sacrum among patients with ODI > 40%, unlike patients with ODI < 40% (Kyrölä et al. 2018). To date no literature exists on the preferred sacral reference for the measurement of the PI and other spinopelvic parameters in L6 populations.

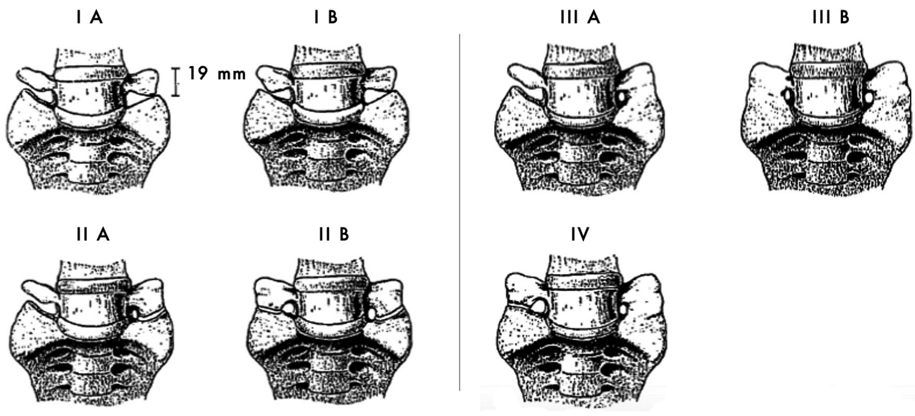


Figure 17. The lumbosacral transitional vertebrae (LSTV). The transitions can be unilateral (A) or bilateral (B) and articulating (2 and 4) or fused (3). In type I there is no articulation or fusion to the sacrum or ilium. (© 1984 From Lumbosacral transitional vertebrae and their relationship with lumbar extradural defects by Castellvi, Goldstein and Chan. Reproduced by permission of Wolters Kluwer.)

2.5.3 Development of adult deformity classifications

Disease-specific classification systems have been developed to categorise pathologic conditions and provide treatment options for different stages of the disease. An ideal classification presents the structured features of different severities of the disease, facilitating reproducible and reliable communication between clinicians and researchers. For optimal clinical use, the classification should assist the development of treatment guidelines and comparison of treatment outcomes (Bess et al. 2013). The classification of spinal deformity started from paediatric spinal deformities. The King-Moe classification was the first widely adapted classification system to provide a treatment algorithm (King et al. 1983). The King-Moe system comprised deformities in the coronal plane only. Twenty years later it was replaced with a more comprehensive classification, which also included some characteristics of sagittal deformity in the AIS (Lenke et al. 2001). Neither of these paediatric and adolescent spinal deformity classifications met the requirements for adult deformity treatment due to the heterogeneity of the aetiologies of ASD and pain and disability as the main drivers for treatment. An ASD classification must include the main predictors of pain and include the characteristics of the 3D deformity and sagittal modifiers that are fundamental in ASD. The earliest versions of an ASD classification were descriptive of the aetiology (Aebi 2005) or built on anatomy and the King/Moe and Lenke classifications (Lowe et al. 2006), but lacked clinical relevance. Therefore, the Scoliosis Research Society (SRS) began developing a specific classification for ASD. The background studies included numerous publications on the correlations between clinical symptoms and radiographs (Schwab et al. 2002, Legaye and Duval-Beaupere. 2005, Glassman et al. 2005a) and on the impact of sagittal balance on ASD (Schwab et al. 2005a, Glassman et al. 2005b, Schwab et al. 2005b). The initial ASD classification has been published (Schwab et al. 2007) and its contents are described in **Table 3**.

Table 3. Contents of the Adult Spinal Deformity Classification published by Schwab et al. 2007.

Type: Location of the deformity (apex of major curve)	I	Thoracic-only scoliosis (no thoracolumbar or lumbar component)
	II	Upper thoracic major, apex T4–T8 (with thoracolumbar or lumbar curve)
	III	Lower thoracic major, apex T9–T10 (with thoracolumbar/
	IV	Thoracolumbar major curve, apex T11–L1 (with any other minor curve)
	V	Lumbar major curve, apex L2–L4 (with any other minor curve)
	K	Deformity in the sagittal plane only
Lordosis modifier: Sagittal Cobb angle from T12–S1	A: B: C:	marked lordosis > 40° moderate lordosis 0° - 40° no lordosis present Cobb < 0°
Subluxation modifier: Frontal or sagittal plane (anterior or posterior), maximum value	0: +: ++:	no subluxation subluxation 1 - 6 mm subluxation > 7 mm
Global Balance modifier: Sagittal plane C7 offset from posterior superior corner S1	N: P: VP:	normal (0–4 cm) positive (4–9.5 cm) very positive (> 9.5 cm)

Increased intervertebral displacement and loss of lumbar lordosis and global balance correlate with poor HRQoL. However, further research showed that these variables did not provide a complete picture of the spinopelvic deformity in ASD. The importance of PI was emphasised in the earlier French studies (Legaye et al. 1998, Vialle et al. 2005) and it became one of the key parameters of the succeeding ASD classifications. As an anatomical measure, PI alone provides limited information; however, the relationship between PI and LL included both HRQoL-related information pertaining to the spinopelvic alignment and the reconstructive requirements for surgery. Fundamental to the next version of the classification were studies on pelvic tilt and truncal inclination (Lafage et al. 2009), sagittal plane and the pelvis (Schwab et al. 2009) and the key parameters that influence the outcome of ASD surgery (Schwab et al. 2010). The combination of PT, PI-LL mismatch and SVA were found to be good predictors of disability and HRQoL in ASD, and the final version of the SRS-Schwab ASD classification was published in a validation study (Schwab et al. 2012) (**Table 4**). The cut-off values of the modifier grades were generated using the PRO scores published in previous studies (Glassman et al. 2005a, Lafage et al. 2009) and tested in the validation study. The 21 ASD patients in the validation study were selected to represent the distribution of classification grades.

Table 4. The SRS-Schwab classification for adult spinal deformity.

SRS-Schwab classification for adult spinal deformity			
Coronal Curve Types		**Sagittal modifiers**	
T	Thoracic only Lumbar curve < 30°	**PI minus LL**	0: within 10° + : moderate 10-20° ++: marked > 20°
L	TL/Lumbar only Thoracic curve < 30°	**Global alignment**	0: SVA < 4 cm +: SVA 4 to 9.5 cm ++: SVA > 9.5cm
D	Double curve T and TL/L curve > 30°	**Pelvic tilt**	0: PT < 20° +: PT 20-30° ++: PT > 30°
N	No major coronal deformity All coronal curves < 30°		

The new SRS-Schwab ASD classification was tested in a prospective multicentre study by the International Spine Study Group and found capable of predicting patients' disability as well as providing a guide to patient assessment for making therapeutic decisions (Schwab et al. 2013). The study group also set the threshold values of the classification's sagittal modifiers for severe disability (ODI > 40%): PT ≥ 22°, SVA ≥ 47 mm and PI-LL ≥ 11°.

The SRS-Schwab ASD classification has since been tested in different countries with good repeatability and reliability (Terran et al. 2013, Liu et al. 2013, Nielsen et al. 2014, Hallager et al. 2016). Berjano and Lamartina (2014) criticized the SRS-Schwab ASD classification for not including clear guidelines for the correction of adult degenerative regional curves, which differ from AIS curves. The majority of de-novo adult coronal curves are in the L and N classes in the SRS-Schwab classification. Clinical concerns about the extension of the fusion area, the aggressiveness of the surgery and postoperative functional limitations were not satisfactorily covered by the SRS-Schwab ASD classification. The rationale of Berjano and Lamartina was to find indications for selective fusions to reduce surgical risk and maintain the mobility of the spine as much as possible by defining degenerative segment disease (DSD). They also wanted to reduce the risk for early junctional disease and to select the optimal methods for correction of sagittal malalignment. They published a treatment-orientated classification system, which is described in **Table 5**.

Ha et al. (2016) also found that the correlation of the SRS-Schwab classification with clinical parameters like the ODI was insufficient, although some spinopelvic parameters showed statistically significant variation in surgical treatment. They concluded that in degenerative lumbar scoliosis neurological compromise has a stronger effect on HRQoL than the radiologically visualised deformity. No single classification can yet provide all the characteristics required for an excellent ASD classification (Bess et al. 2013). Thus far, the SRS-Schwab ASD classification is the only simple, valid and widely used instrument despite of its weaknesses in guiding surgical techniques or recognizing extra-deformity morbidity.

There is also a lack of research and knowledge on sagittal disorders, disability, and the quality of life of patients with symptomatic degenerative spinal conditions that precede the development of ASD. Despite the fact that the evaluation of the entire spine would improve the technical planning of surgery, some patients with moderate spinal deformity will unfortunately experience lower back fusion surgery without imaging of the spinal alignment (Maggio et al. 2015, Barrey and Darnis. 2015, Le Huec et al. 2015b)

Table 5. Types of adult degenerative segment disease (DSD) and suggested methods of surgery. Modified from Berjano and Lamartina (2014): Classification of degenerative segment disease in adults with deformity of the lumbar or thoracolumbar spine. Eur Spine J 2014; 23:1815-1824.

Type	Symptoms	Surgical site
Type I Local nonapical DSD Balanced	No symptomatic segments in apical area of the main curve	Surgery limited to symptomatic segment (decompression, short fusion) is indicated. On L4-5 level, if presacral level is degeneratic or spondylolytic, include lumbosacral junction in fusion.
Type II Limited apical DSD Balanced	LL loss < 25° Coronal Cobb angle < 25°	Fusion across the apex of the coronal curve. Apex in vertebra: fusion one level above and below. Apex in disc: 1-2 vertebrae above and below the disc.
Type III Extensive apical and nonapical DSD Balanced or minor imbalance	Coronal Cobb angle > 25° Symptomatic DSD in whole main curve or beyond	Fusion of the main curve and extended to LS and/or TL junctions if needed.
Type IV Imbalanced spine • Sagittal imbalance • Coronal and sagittal imbalance	Loss of LL > 25° Sagittal deformity not flexible and corrected in extension radiographs	Correction of the deformity with osteotomies and/or aggressive release (3CO, ALIF, SPO, Ponte osteotomy, VCR)

2.6 Patient-reported outcome measures (PROM) in spinal disorders

PROMs are as crucial as radiographic and surgical details in measuring the results of a treatment or a surgical intervention (Baldus et al. 2011a). Numerous PROMs exist to measure disability and HRQoL but as yet no consensus has been reached on which set of instruments would be best suited to measure adult spinal deformities (Faraj et al. 2017). To achieve good reliability and repeatability in clinical and research work, the instrument should be targeted for its purpose and be sensitive to patients' linguistic and cultural differences. The PRO instruments should have adequate internal consistency and be responsive to change induced by treatment interventions. The combination of PROM instruments used typically includes a generic questionnaire, e.g. the SF-36 (or RAND-36) (Hays and Morales 2001) or the EQ-5D (EuroQol Group. 1990), and instruments that measure pain and disability related to spinal diseases, e.g. the VAS (Price et al. 1983) or the ODI (Fairbank and Pynsent 2000). For spinal deformities, both specific and super-specific PROMs are available. The super-specific instruments include, for example, the Walter-Reed Visual Assessment Scale (WRVAS), Spinal Appearance Questionnaire (SAQ), Trunk Appearance Perception Scale (TAPS) and national versions other instruments adapted for measuring spinal deformation. These super-specific instruments are targeted to the treatment of paediatric or adolescent scoliosis and have not been validated among adults or have potential as instruments for generalized use in spinal conditions. The development of scoliosis-specific instruments started in Spain with the QLPSD (Quality of Life Profile for Spine Deformities) (Climent et al. 1995) instrument designed to measure the treatment results of bracing and surgery in cases of AIS.

2.6.1 Scoliosis Research Society questionnaires

Haher et al. (1999) published the first SRS instrument (version 24) for the measurement of HRQoL among patients with adolescent idiopathic scoliosis. The questionnaire items are based on a 5-level symmetrical agree-disagree Likert scale. Asher et al. (2000, 2003a and 2006) further developed the instrument, incorporated similar domains and added the mental health domain to create the 23-question pattern. The seven postoperative questions were developed and included in the present SRS-30 questionnaire, which was introduced in 2003. The SRS-30 encompasses versions 22 and 24. The questionnaire and scoring information are free and available at the Scoliosis Research Society webpage www.srs.org. Asher et al. (2003b) also found the SRS-22 instrument responsive to change associated with surgery among adolescents but for post-surgery use the more comprehensive SRS-30 version was subsequently developed.

In May 2018, Ovid Medline identified 16 linguistic and cultural validation studies of the SRS-22 or the revised SRS-22r among patients with adolescent idiopathic scoliosis, including American English original versions, a French Canadian version validated in both Quebec and in France (Beauséjour et al. 2009, Lonjon et al. 2014), Korean (Lee et al. 2011), and translation and adaptation studies in Chinese (2 different) (Li et al. 2009, Cheung et al. 2007), Japanese (Hashimoto et al. 2007), Turkish (Alanay et al. 2005), Arabic (Haidar et al. 2015), Danish (Simony et al. 2016), Dutch (Schlosser et al. 2014), Spanish (Bago et al. 2004), Italian (Monticone et al. 2010), Greek (Potoupnis et al. 2012), German (Niemeyer et al. 2009) and Persian (Mousavi et al. 2010).

Three validation studies of the SRS-22 versions among adults were identified in the Ovid Medline database. Berven et al. (2003) found the American English SRS-22 to be a reliable and reproducible instrument among adult patients with scoliosis compared to asymptomatic controls in a validity assessment with the SF-36. Bridwell et al. (2007) studied the responsiveness of the SRS-22 to surgery among adults and Mannion et al. (2018a) analysed the structural validity of the published trans-culturally adapted and translated English, Spanish, French, Turkish and German (Asher et al. 2003, Bago et al. 2004, Beauséjour et al. 2009, Alanay et al. 2005, Niemeyer et al. 2009) versions of the SRS-22 instrument. Prior to this, Monticone et al. (2010) had found that the quality of the linguistic and trans-cultural validation studies was mostly poor or moderate and that the validation process was not adequately described in the publications. No previous linguistic- cultural adaptation and validation studies of any versions of the SRS questionnaires on adolescents or adults in the Finnish population have been published.

The further development of the SRS-22 continues with psychometric studies of the structural validity of the instrument for adolescent (Caronni et al. 2014, Jain et al. 2015) and ASD patients (Jain et al. 2016). Assessing the psychometric and structural properties of the PROM increases measurement reliability and helps to understand the strengths and weaknesses of the instrument in a specific patient cohort. The psychometric and structural validity of a questionnaire can be tested with several methods. The Rasch analytic theory is a frequently used complex mathematic model suitable for evaluating the measurement properties of a questionnaire (Rasch 1993, Roberts et al. 2012). In previous studies, the multidimensional SRS-22 instrument was found to be a valid measure of HRQoL among patients with AIS. However, after the psychometric structural Rasch analysis a linear and unidimensional SRS-7 with different psychometric properties was introduced (Caronni et al. 2014, Jain et al. 2015). On one hand, the modified, short version of the SRS-7 is supported by better responsiveness, less difficult questions designed to take into account all test-takers, and a linear interval scale for reporting the results instead of the ordinal and uneven distribution used in the full version. On the other hand, a multidimensional full version of the instrument is expected to be better for evaluating changes in individual aspects of the domains (Mannion et al. 2018a).

Literature on the validation of the SRS-30 is scarce. A systematic electronic search of data on the SRS-30 instrument was carried out on 20th May 2018 including Ovid Medline, Cochrane Library, Scopus and Cinahl databases. The search comprised titles, keywords and abstracts. The search terms are presented in **Table 6**. The search results were divided into three categories: SRS-30 among adults, SRS-30 among paediatric and adolescent subjects and SRS-30 validation studies (**Table 7**).

Table 6. List of terms used in the systematic electronic search.

Systematic data search issues
Scoliosis research society (proximity/3) 30
SRS-30
Questionnaire
Patient reported outcome
Health related quality of life, HRQoL
Validation

Table 7. The numbers and categories of publications on the SRS-30 instrument found in a systematic review of literature.

	Published between years:	SRS-30 adults age >18 years	SRS-30 adolescent and pediatric	SRS-30 validation studies
Cochrane	2013-2017	2	5	0
Scopus	2006-2018	14	35	2
Ovid Medline	2006-2018	16	43	2
CINAHL	2009-2017	4	8	1

The systematic review of the literature found no previous reports on the translation, trans-cultural adaptation and validation of the SRS-30 among adult patients. Carrico et al. (2012) published a validation study of the SRS-30 among Brazilian Portuguese adolescents with scoliosis. Baldus et al. (2011b) described the SRS-30 values in a normative adult population among American English-speaking individuals from different states of the USA. The comparison of normative SF-36 levels was conducted among American and Canadian populations.

Faraj et al. (2017) reviewed the frequency and clinimetric properties (Fava et al. 2012 and Marx et al. 1999) of the PROMs used in reports on ASD. The two most frequently used PROMs were the ODI and the SRS-22, which were used in 44% of studies whereas the SRS-30 was used in 7.6% of the eligible adult spinal deformity studies. The quantity of clinimetric studies on PROMs among ASD patients was low. The ODI and the SRS-22 were the most commonly evaluated instruments and their clinimetric properties were most favourable among ASD patients. The present research group found no studies on the clinimetric properties of the SRS-30 among adult patients published before December 2016.

The literature indicated that spinal deformation in adults is a gradual process in which structural changes and symptoms increase individually. The concept of spinal alignment and balance is thus needed for a wider range of patients than only those with severe spinal deformities. The ODI identifies chronic back pain-related disability and distress in daily life and a culturally and psychometrically valid version (2.0) is available in Finnish. A disease-specific HRQoL instrument for adult spinal degeneration patients was needed to improve measurement of the effectiveness and value of ASD treatment. The SRS-22 is currently the best documented spinal deformity-specific HRQoL instrument, although use of the SRS-30 is increasing in evaluating surgical patients. The SRS-22, which is widely used internationally, is problematic in that the translated versions have been made from different revised versions and hence comparison is slightly biased. As the SRS-30 encompasses earlier revised versions 22 and 24, it remains the most comprehensive SRS instrument. The SRS-30 has been found applicable to a wide range of adult and adolescent patients with spinal deformities. Further studies are needed to evaluate the psychometric and structural validity of the SRS-30 and thus identify the strengths and weaknesses of the instrument when used with patient cohorts that are culturally and demographically diverse.

2.7 Treatment of ASD

2.7.1 Sagittal balance

Maintaining an erect position with increasing sagittal or coronal malalignment causes fatigue and pain in the buttocks, spine, and thighs (Glassman et al. 2005b), and hence treatment should cover both compensatory mechanisms and loss of truncal inclination. In ASD, loss of sagittal balance is more typical than severe symptomatic coronal malalignment. A comprehensive analysis of the factors underlying sagittal imbalance is essential. Skeletal alignment should be estimated without the bias introduced by compensatory mechanisms. Reliable radiological assumptions can be achieved if full spine standing radiographs and

PACS measurement tools are combined with meticulous patient positioning and careful evaluation of compensatory mechanisms. The most reliable combination is a full body 3D image combined with semiautomatic measurement and calculation software, which also allows pre-surgery simulation of the deformity correction (Lafage et al. 2015). Evaluation of the effects of extraskeletal pathologies on sagittal malalignment, such as age (Lafage et al. 2016b), neuromuscular and psychiatric diseases, function and obesity (Araujo et al. 2014), and of medical conditions that may affect muscular control of the body should be included in the clinical examination.

2.7.2 Conservative treatment

Disability due to spinal deformities has been described for thousands of years. Solutions to alleviate the problem have been sought since ancient times, and the first reports of conservative treatment methods go back to the Greeks of the Classical era in the 5th century BC. One of the most famous and widely depicted historic individuals with a spinal deformity was the Macedonian warrior Alexander the Great (356-323 BC), whose sudden death may have resulted from a congenital scoliotic syndrome with cervical deformity (Ashrafian 2004). This theory has, however, been criticized for retrospective deduction. Hippocrates (c. 460 – 370 BC) described the earliest recorded methods for correcting a deformity: axial traction was used to separate the joint surfaces without rupturing the binding ligaments. Devices known as the Hippocratic ladder, board and scamnum (**Figure 18**) were introduced (Vasiliadis et al. 2009) to treat spinal deformities. Another Greek physician in the Roman Empire, Claudius Galenus (129 – c. 200/216 AD), gave spinal curves their modern names: scoliosis, kyphosis and lordosis (Tarpada et al. 2016) and further developed the treatment devices used in the Hippocratic era (**Figure 18**).

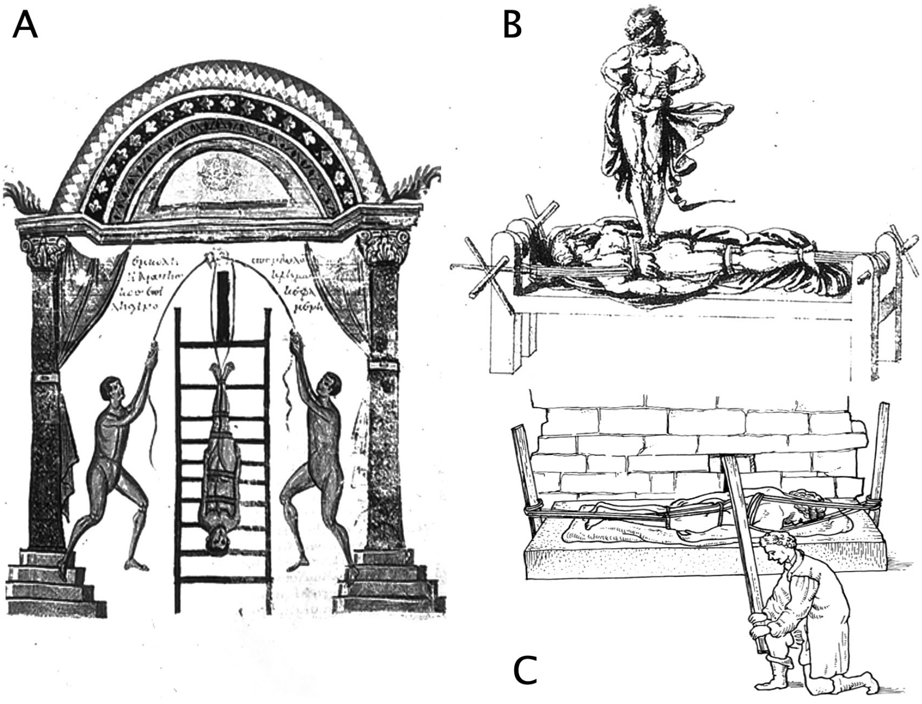


Figure 18. The Hippocratic ladder (A), board (B) and Galen's version of the scamnum (C) to correct spinal deformities. (© Open Access 2009 From Historical overview of spinal deformities in ancient Greece by Vasiliadis, Griva and Kaspiris. Scoliosis 2009;4:6,7161-4-6. BioMed Central Ltd part of Springer Nature.)

Images of stationary bracing for spinal deformity have been dated as far back as 3 500 BC in Crete. In 1772 Francois Levacher of the University of Paris combined these two treatment philosophies and introduced the first brace allowing axial distraction in the upright position and patient mobilization during treatment (Meredith and Vaccaro 2014). Bracing continues to be a method of choice to control curvature of the growing spine; however, ASD brace treatment suffers from problems of compliance with the long duration of treatment and progression of sagittal deformity and spinal stenosis (de Mauroy et al. 2016).

To study non-surgical treatment of ASD, Glassman et al. (2006) analysed patients who, on their first consultation for ASD, were assigned to non-surgical treatment with consent of both patient and surgeon. The patients were divided into high (ODI score > 20) and low symptom (ODI score < 20) groups and the quantity and modalities of the conservative treatment were analysed. The conservative treatment of the low-symptom patients included exercise, analgesics or NSAIDs, pain management or no treatment at all. The high-symptom patients received narcotics, epidural and nerve root blocks, physical agent methods, analgesics, pain management referral, bed rest, strength training and stabilization exercises. No specific physical medicine or rehabilitation protocols were described. Although the physical functioning of the low symptoms group paralleled that of the general population, they received almost the same amount of non-surgical therapies as the high symptoms group, whose disability and deformity profile resembled that of the ASD patients who had been selected for surgical treatment at study outset. Although a significant proportion of the western population is overweight or obese, a factor that can render sagittal balance positive and symptomatic, (Araujo et al. 2014) no diet or weight control recommendations were included among the conservative treatment modalities. Liu et al. (2016) conducted a follow-up study of a non-surgical cohort with the aim of identifying the baseline factors that indicate poor response to conservative treatment. In both the above studies, overlap was present in the variables and spinal deformities across the different study groups, and the non-surgical treatment was not standardized. The problem in comparing surgical with non-surgical treatment lies in the greater heterogeneity of the non-surgical population. Non-surgical groups have often included patients who did not respond well to conservative treatment and were in many aspects comparable with those in the surgical treatment groups.

The literature shows no support for conservative treatment as a preferred method in ASD. Evidence on specific treatments is lacking and support is confined to small case studies and expert opinions (Everett and Patel 2007). Activity modification and anti-inflammatory medications similar to those used in other common aging-related degenerative musculoskeletal conditions can be recommended but beyond this no evidence exists on efficacy or safety. Only a few physical rehabilitation protocols for spinal deformity have been described. These include exercise for disability caused by AIS (Anwer et al. 2015) or for age-related hyperkyphotic posture (Bansal et al. 2014). The non-operative treatments used are often an assortment of physical therapies, injections, medication, and observation.

It is difficult to conduct a randomized trial in ASD due to heterogeneity in patients' age, co-morbidities and symptoms as well as in types of deformity. Surgeon-related preferences and opinions and patient satisfaction with the surgeon can also influence decision-making between treatment alternatives. In the study of adult symptomatic lumbar scoliosis patients by Neuman et al. (2016), randomization was one objective. While the research group strongly recommended patient randomization, for patients who refused, the treatment option was chosen in accordance with the surgeons' and patients' preferences. Of the 295 candidates for primary surgery, only 67 patients agreed to randomization. These patients resembled those chosen for surgical treatment without randomization. Those who preferred surgical treatment felt they had exhausted all the non-surgical treatment possibilities and those who opted for non-surgical treatment were not interested in surgery at the time of the consultation.

As in the aforementioned studies of non-surgical ASD treatment, in the studies comparing surgical and non-surgical treatment the decision to pursue operative management has also been determined by the individual patient and surgeon, and the conservative treatment given has not been standardized. In two recent prospective multicentre studies (Smith et al. 2016, Scheer et al. 2018b), propensity matching of the baseline clinical and deformity-related data was used to avoid bias between the treatment comparison groups. Smith et al. (2016) found that operative treatment for ASD yielded significant improvement in HRQOL at the minimum 2-year follow-up, whereas non-surgical treatment on average did not reduce baseline levels of pain and disability. Scheer et al. (2018a) found that operative treatment of ASD resulted in significantly higher QALYs and a greater positive change in QALYs at 2-3 year postoperative evaluations compared to non-surgical treatment. These two studies are in line with most of the literature on the risks and benefits of ASD surgery. To conclude, operative treatment was usually chosen for patients with neurological deficit or pain restricting daily activities, severe spinal malalignments and related disability or when symptoms were not responsive to conservative treatment.

2.7.3 Operative treatment

Patient selection and risk evaluation

In selecting candidates for high-risk surgery, such as in ASD, an adequate preoperative risk evaluation using the known predictors of adverse effects is mandatory. Due to the complex pathologies of ASD, tissue-sparing mini-invasive techniques often cannot be utilized for fear of iatrogenic complications and insufficient correction. The surgical trauma (**Figure 19**) and healing capacity needed to avoid wound-related problems and achieve bone fusion causes of considerable distress to an ASD patient.

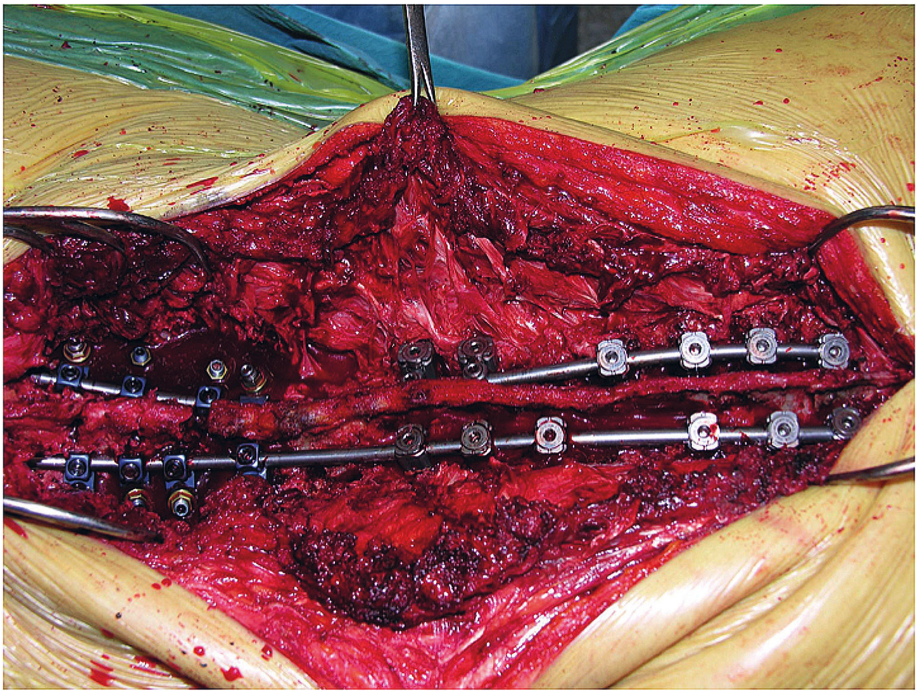


Figure 19. Thoracolumbar ASD: posterior open approach, correction, instrumentation and decompression. Cement augmentation of screws in peri-osteotomy levels in an osteoporotic patient with the year 2007 technique.

Mirza et al. (2008) developed and validated an index to quantify the complexity of spine surgery. The index is not fully capable of detecting surgical method-related risks in ASD surgery. To predict complications, Yoshida et al. (2017) published a “Sliding Scale” of risk factors with age-related and ASA-class threshold values. The scale is based on a retrospective cohort of operated ASD patients and their complications. The independent factors for perioperative complications were age > 70 years, operation time > 6 hours, estimated blood loss (EBL) > 2 litres, ASA physical status class >3 and fusion segments > 10. It is recommended that, to avoid complications, the higher the patient’s age or ASA status, the less aggressive the surgery, measured as operation time, and the lower the EBL should be.

The concept of frailty is a physiological diagnosis and measurement of the impact of aging. It represents the health status of an individual better than chronological age alone. Frailty is characterised by diminished strength and endurance and reduced physiological function, factors that may impair self-management and/or increase the risk for death. The surgical Frailty Index (Farhat et al. 2012) was further developed and validated as the Adult Spinal Deformity Frailty Index (ASD-FI) by Miller et al. (2018) in a multicentre study with North American and European ASD patient cohorts. Severely frail patients are prone to complications and longer hospital stay after ASD corrective surgery. The validated index contained 36 items answered on a dichotomous response scale as either 'no' or 'yes' (0/1), Scores are summed and divided by the number of questions answered. The index values are < 0.3 = not frail, 0.3 – 0.5 = frail and > 0.5 severely frail. The index questions also serve as a basic health questionnaire for surgical patients and the PROMs used in the preoperative evaluation, e.g. SF-36, SRS instruments and ODI. The ASD-FI is currently under further development but remains applicable in its present form for clinical risk evaluation **(Table 8).**

Table 8. The Adult Spinal Deformity Frailty Index (ASD-FI) items according to Miller and coworkers (Miller et al. 2018).

Reported by health care professional or from patient records	Patient reported data	
> 3 Medical problems	Bladder incontinence	Inability to cheer up often
Anemia	Bowel incontinence	Inability to do normal work/ school/housework
BMI < 18.5 or > 30 kg/m^2	Deteriorating health this year	Inability to lift heavy objects
Cancer	Difficulty in climbing 1 flight of stairs	Inability to travel > 1 hour
Cardiac disease	Difficulty driving a car	Inability to walk without assistive device
Currently on disability	Difficulty getting dressed	Loss of balance
Depression	Difficulty getting in/out of bed	Not in excellent health
Diabetes	Difficulty sleeping > 6 hours	Restricted activity level
Hypertension	Difficulty walking 100 m	Weakness
Kidney disease	Personal care dependency	Feeling depressed most of the time
Liver disease	Restricted social life	Feeling tired most of the time
Lung disease	Difficulty with light activity	Feeling worn out most of the time
Osteoporosis	Inability to bathe without assistance	General health: fair = 0/poor = 1
Peripheral vascular disease		
Previous blood clot (DVT, PE, stroke)		
Nervous system disorders		
Smoker		

Each item is answered either "no" = 0 or "yes" = 1
Sum of items is divided by the number of answered questions = ASD-Frailty Index.
ASD-FI < 0.3 = No frailty
ASD-FI 0.3 – 0.5 = Frail
ASD-FI > 0.5 = Severe frailty

Lee et al. (2017) reported risk factors for morbidity and mortality in ASD surgery. The patient-related risks for morbidity were high age, female sex, ASA class ≥3, dyspnoea, steroid use, hypertension requiring medication, renal failure and bleeding disorder. The risk of mortality was higher if the patient was ventilator-dependent, in dialysis or had recently lost weight without dieting. The operation-related risks for mortality and morbidity were operation duration > 4 hours, fusion length > 3 levels and anterior procedure. Osteotomy, fusion to pelvis and use of intervertebral devices increased the risk for morbidity but not mortality (Lee et al. 2017).

Based on a literature review and expert consensus, Pellisé et al. (2018) constructed a more comprehensive risk evaluation tool, the Adult Deformity Surgery Complexity Index (ADSCI). They wanted to include patient characteristics, disease attributes and treatment factors in the risk calculator. The ADSCI improved risk estimates compared with the more generic Mirza index; however, the research group concluded that we should probably accept that no surgical complexity index alone will ever be able to totally predict the occurrence of a complication (Pellise et al. 2018).

Surgical methods – fusion and instrumentation

The typical indication for preliminary ASD surgery was decompression and fusion of the kyphosis caused by Pott's disease (Sorrel and Sorrel-DeJerine 1947). The pioneers of spinal fusion were Russel A. Hibbs, who developed the subperiosteal fusion of spinous processes to stabilize tuberculotic deformities (Miller and Vitale 2015), and Fritz Lange, who performed the first fusion surgeries in adolescent scoliosis patients with a combination of celluloid bars, steel and silk wiring in 1910 (Lange 1986). The earliest report of anterior column support with a tibial bone graft in 1911 was inspired by Dr Hibbs' work and also related to spinal tuberculosis (Albee 2007). The earliest report of internal fixation of the spine is from year 1891 by Dr Berthold Hadra who accomplished fusion and stabilisation of a spinal fracture dislocation by wrapping wires around the spinal column (Keller and Holland 1997, Tarpada et al. 2016). Internal fixation to fuse the kyphotic lesion and prevent progression of the deformity is one of the earliest examples of adult-instrumented deformity surgery (Cobey 1951, Lange 1986). In 1953-55, Paul Harrington designed the first surgical implants to correct scoliotic curves with an implant. The Harrington rod (Harrington 1963) and its derivatives (e.g. the Wisconsin rod) were introduced in surgery for AIS. The distraction rods were designed to correct flexible coronal curves and were not optimal for ASD. Before pedicle screw instrumentations, the Luque-Galveston instrumentation, with flexible rods, was used (Boachie-Adjei et al. 1991). The construction comprises vertical rods contoured to targeted sagittal and coronal shapes of the spine. The inferior parts could be bent and inserted into pelvis between the laminae of the posterior iliac bone. The rods were attached to the spine with sublaminar wires, which were popularized by Dr Eduardo Luque. Surgery for rigid deformities in adults was often staged so that anterior release was performed first and the posterior instrumentation and spine re-contouring in a second operation. The first experiences of hooks and early sacral screws in adults were not as promising as in AIS surgery (Devlin et al. 1991), when the modified Cotrel-Dubousset (1984) instrumentation was introduced in treatment of ASD. Deformity surgery in adults was found technically more demanding than AIS correction, but patient outcome in these pioneering operations was promising (Albert et al. 1995). Experience with pedicle screws grew, and with the pedicle-probing technique screw-related complications decreased (Boachie-Adjei et al. 2000). To decrease medical complications, the staging of both the anterior-posterior and posterior-posterior phases into two operations with a short recovery interval was found safe and useful (Rhee et al. 2003). Steel screw-rod instrumentations became the most popular method of correction for ASD after the Isola-instrumentation, which offers better de-rotation and deformity control capacity with solid screws, was introduced (Benli et al. 2001). Eventually, when the safety and efficiency of thoracic pedicle screws in ASD were established, hybrid screw-hook instrumentations changed to all-pedicle screw constructs (Bess et al. 2007). Anterior lumbar interbody fusion (ALIF) was introduced in the early 1980s with bone grafts (Crock. 1982) and introduced to ASD surgery in the 1990s (Bridwell et al. 1995, Kleinstück et al. 2002). Titanium and polyetheretherketone (PEEK) cages (**Figure 20**) were developed for low back surgery and later adopted in deformity surgery to replace bone grafts.

Kyphosis of the proximal junction (PJK) of instrumentation and non-instrumented spine is a post-surgical phenomenon that may lead to loss of sagittal alignment, neurological deficit and reoperations due to proximal junction failure (PJF). Thus, the polymethylmethacrylate (PMMA) bone cement used in joint replacement surgeries and vertebroplasties was also utilized in spinal surgery to augment the proximal junction of the instrumentation. Ghobrial et al. (2017) reported that prophylactic augmentation of the upper instrumented vertebra (UIV) and the immediately above vertebra with vertebroplasty cement appeared to prevent the development of PJK and proximal junctional failure (PJF). The method has been proven effective and safe regardless of concerns about cement leakage to spinal canal or vena azygos or v.cava, or even to the heart and pulmonary cement embolisms (Martín-Fernández et al. 2017).

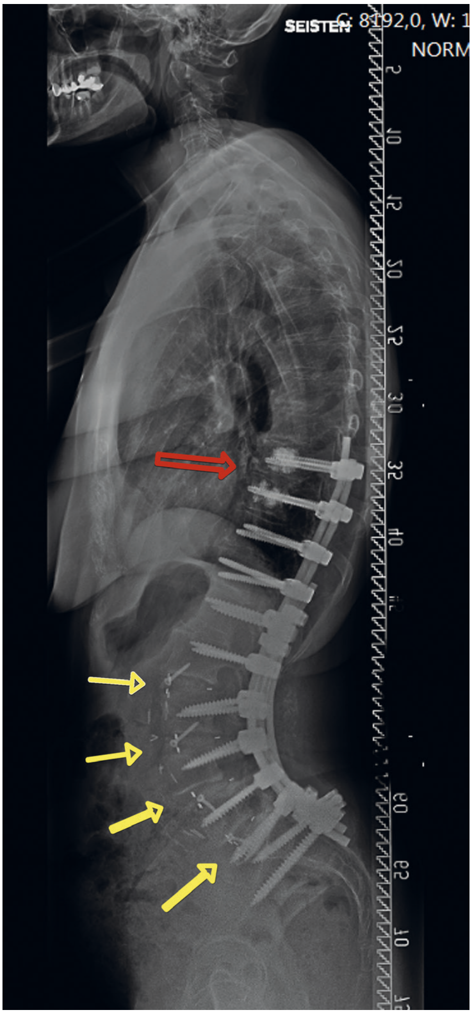


Figure 20. Anterior lumbar interbody fusion with PEEK cages (yellow arrows) fixed temporarily with titanium screws to avoid dislocation during positioning for posterior surgery. Proximal pedicle screws are cement-augmented (red arrow).

The modern problems of ASD surgery have emerged as developing techniques have lured surgeons into operating on cases, which would not have been operated on with the earlier surgical methods. Problems related to the optimal instrumentation area, especially above or below the LS junction (Farcy et al. 1992, Edwards et al. 2004), pseudoarthrosis and rod breakage (Kim et al. 2006, Gupta et al. 2018), PJK and PJF (Glattes et al. 2005) and affisions to neural elements (Pateder and Kostuik. 2005) are currently topics of debate and research (Scheer et al. 2017). A PI-based Global Alignment and Proportion (GAP) score has finally been developed to predict mechanical complications arising from ASD surgery (Yilgor et al. 2017a).

Surgical methods – deformity correction

The localization, rigidity and length of the deformity, concomitant spinal stenosis, age and co-morbidities dictate the alternatives for correcting the spinal alignment. In ASD, the main surgical target is reconstruction of the optimal PI-related LL and TK. RLL and LDI derived from PI-related lordosis and the lordosis distribution could result in better long-term HRQoL results and help prevent mechanical complications. However, they only became available quite recently, and wider experience of and validation data on these novel parameters are needed (Yilgor et al. 2017b). Correction of a deformity of the adult spine can be approached using the anterior, posterior or a combination of both techniques (Passias et al. 2017). Recently, lateral mini-invasive techniques have also been introduced to ASD surgery with promising results on coronal curves but limited correction on lumbar lordosis and sagittal alignment (Phan et al. 2015) and no knowledge on long-term outcomes.

Schwab et al. (2015) published a comprehensive anatomical osteotomy classification for the posterior techniques used to correct different grades of sagittal deformity (**Figure 21**). Posterior osteotomies can be combined with anterior releases or grafting with cages or bone graft. The Smith-Petersen osteotomies (SPO)(Smith-Petersen et al. 1969) and Ponte osteotomies (Suh et al. 2012) are typically used as a series of multiple posterior facet or facet and pars interarticularis osteotomies to reduce flexible kyphotic deformity. The SPO is an open-wedge partial facet osteotomy and requires a mobile disc. The Ponte osteotomy is a closing-wedge osteotomy, which also requires a mobile anterior column. The whole facet, spinous process and ligamentum flavum are resected. The correction potential of the SPO and Ponte-type osteotomies is 5°-10° per level. In ASD surgery, these posterior column resections can be combined with anterior release and grafting with ALIF implants or bone graft to reduce lumbar coronal curve and enlarge LL. A three-column (3CO) pedicle subtraction osteotomy (PSO) (Boachie-Adjei et al. 2006) closes an even larger wedge bone-to-bone within the same vertebra, with a correction potential of 25°-35° at any level (Bridwell 2006). The eggshell procedure (Heinig 1984) was a predecessor of the PSO. When more correction on a single level is required than PSO can provide, the adjacent superior disc can be included in the resection. Anterior support with bone or a cage is often included in this osteotomy technique to prevent AP dislocation of the adjacent vertebrae. To correct rigid kyphosis with high angulation, resection of one or several vertebrae (VCR), adjacent discs (and ribs if in thoracic spine) may be necessary to realign the spine. These procedures can be posterior only but are often combined with anterior support to hinge the correction. In very complex, rigid and often congenital deformities, combinations of these osteotomies on multiple levels may be required despite the surgical risks. Derotation techniques adopted from treatment for adolescent scoliosis are also available in ASD surgery if large mobile or rigid but released coronal curves are present (Shen et al. 2015) (**Figure 22**).

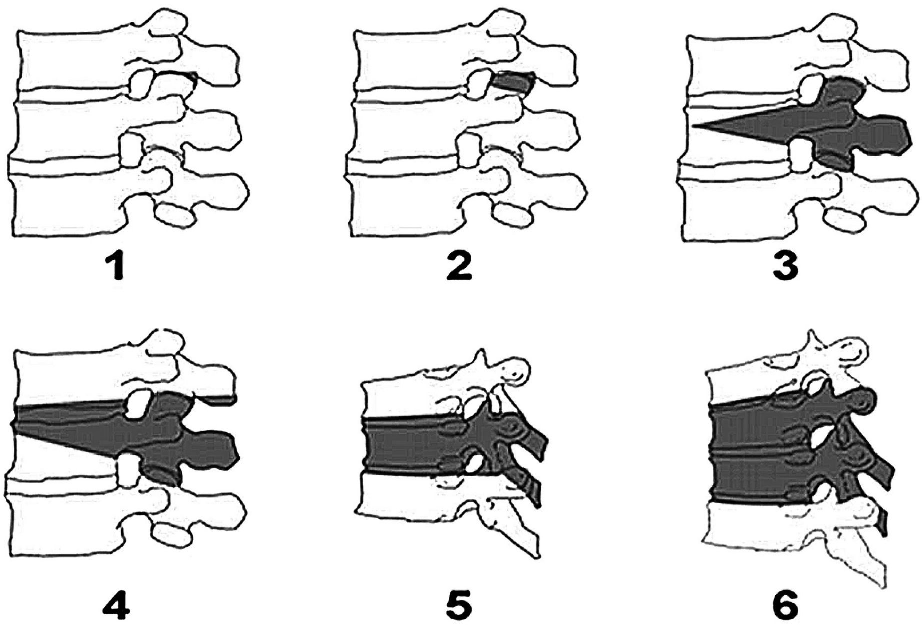


Figure 21. The anatomical osteotomy classification. 1 Smith-Petersen osteotomy (SPO), 2 Ponte osteotomy, 3 Pedicle subtraction osteotomy (PSO) 4 PSO + including posterior disc, 5 Vertebral column resection (VCR) and 6 Multiple VCR. (© 2015 From The comprehensive anatomical spinal osteotomy classification by Schwab et al. Reproduced by permission of Oxford University Press)

Figure 22. Posterior ASD correction derotation is being performed after posterior release with Ponte- and Smith-Petersen osteotomies.

Complications of deformity surgery

Variation between individuals receiving surgery for ASD and the development of multiple surgical techniques hinder reliable comparison of patient cohorts and their complications. Comparing historical materials is not beneficial, as neither the patients nor surgical methods are comparable. Sciubba et al. (2015) updated a comprehensive review of the complications after ASD surgery. The review was limited to the year 2000 or later to include only modern surgical procedures. The authors encountered several sources of bias. Most of the studies were retrospective and thus more likely than prospective studies to underreport complications. Complication reporting was not standardised and the categories of major and minor, early and late, and medical-related and surgery-related complications varied across studies. Moreover, many studies reported a marked amount of complications under the heading "unspecified" rather than attempting to categorise them. Rare complications were also liable to be underreported in most studies (Sciubba et al. 2015b). In all the categories of ASD surgery, the complication rate was 0 to 1.7 per patient. 3CO, while an efficient method to correct severe sagittal deformities, is also associated with the highest complication rates. The main findings of the comprehensive review study on complication rates in ASD surgery by Sciubba et al. (2015) are presented in **Table 9.** Complications that require new surgery constitute the greatest burden on both patients and society. Scheer et al. (2013), in a prospective multicentre study, reported a reoperation rate of 17%, of which 3CO accounted for a higher percentage (19%) than that (16%) of surgery using techniques other than 3CO (Scheer et al. 2013).

Outcome of ASD surgery and patient satisfaction

Mannion et al. (2018b) compared the results of spine and large joint surgeries with a validated joint-specific multidimensional instrument, the Core Outcome Measures Index (COMI). This analysis showed that outcomes were significantly poorer after spine surgery compared to large-joint replacement. The success of surgery seemed to diminish with the increasing complexity of the "motion segment" (hip, knee, spine). The worst outcomes were achieved in ASD surgery. No single best treatment for ASD can be prescribed even when individual patient-dependent variables are taken into account. Patients with moderate disability and deformation have a greater chance of an optimal surgical outcome but little improvement in HRQoL, whereas patients with the poorest baseline HRQoL are more likely to achieve significant improvement in HRQoL but less likely to obtain an optimal surgical outcome (Moal et al. 2015). Conservative treatment may provide higher quality-adjusted life expectancy (QALE) in the short term compared to surgery, probably owing to their higher baseline QALE. Surgical ASD patients show a larger improvement in both QALE and HRQoL measures, especially when their baseline status includes significant disability (Acaroglu et al. 2016). Very long-term follow-up data remain lacking. The pros and cons of the treatment choices in ASD can differ during the different stages of follow up. On one hand, surgery may be better in the long run once the burden of complications in the early phases of recovery have disappeared. On the other hand, the benefits obtained from surgical correction

Table 9. Major or minor preoperative and long-term complications in percentages of the whole group after ASD surgery. Comparison of the adverse effects after all ASD surgery, non-3CO and 3CO procedures. Data from Sciubba et al. 2015.

Surgery groups and complications (%)		Major perioperative	Minor perioperative	Long-term
All 55%	**Overall:**	**18.5 %**	**15.7 %**	**20.5 %**
	Top-5:	3.1 Neurologic deficit	3.0 Dural tear	7.6 Pseudoarthrosis
		3.0 Unspecified requiring surgery	2.1 Ileus, gastrointestinal	3.3 Instrumentation/graft failure
		2.4 Deep wound infection	1.5 Transient neurological deficit	2.9 PJK
		1.3 Instrumentation/graft failure	1.0 Superficial infection, no surgery	2.7 Adjacent level degeneration
		1.2 Excessive bleeding	0.7 DVT	2.0 Symptomatinc instumentation, possibly removal
		3.2 All infections	*3.1 Unspecified*	
		2.1 All respiratory together	*1.0 Mild pulmonary/respiratory*	
Non-3CO 45%	**Overall:**	**8.9 %**	**15.4 %**	**21.2 %**
	Top-5:	*3.1 Overall infections*	3.4 Ileus/gastrointestinal	6.4 Pseudoarthrosis
		2.8 Deep wound infection	3.0 Dural tear	5.2 Instrument/graft failure
		1.4 Neurological deficit	1.7 Urinary tract infection	4.7 Adjacent segment degeneration
		0.9 Overall hematoma (wound, epidural, retroperitoneum)	1.3 Transient neurological deficit	2.0 PJK
		0.6 Instrumentation/graft failure	*1.5 Unspecified or other*	*20.2 Instrument/graft related failure aggregated all*
3CO 66%	**Overall:**	**31.8 %**	**15.0 %**	**18.7 %**
	Top-5:	6.8 Excessive bleeding	3.8 Dural tear	6.4 Pseudoarthrosis
		6.7 Neurological deficit	2.7 Transient neurological deficit	5.8 Instrument/graft failure
		4.9 Unspecified requiring surgery	1.7 Deep vein thrombosis	3.2 PJK
		3.2 Deep wound infection	1.4 Ileus/gastrointestinal	1.5 Vertebral compression fracture
		4.1 Overall infection	*1.2 Unspecified*	*16.7 Overall instrument-related failure*

Top-5 = five most frequent individual complications. *Aggregation of complications of the same anatomical area or aetiology printed in italics.*
3CO = three-column osteotomy of the spine, Non-3CO = adult spinal deformity (ASD) correction with other methods than 3CO
PJK = proximal junctional kyphosis

of spinal imbalance may deteriorate over time and a conservative approach may prove superior to surgery. Even solid instrumented fusion cannot prevent the LL achieved from deteriorating over time (Theologis et al. 2017) when sagittal balance is adversely affected by the sagittal alignment that is inclined anteriorly for other than surgery-related reasons. However, a bigger problem is the loss of the surgically improved alignment from the non-fused kyphotic part of the upper thoracic spine.

The patient's perception of the impact of surgery is paramount. After ASD surgery, the most frequent method of measuring patient satisfaction is the two questions included in the SRS instrument: "Are you satisfied with the results of your back management?" and "Would you have the same management again if you had the same condition?" Somewhat controversial is whether the measurement of patient satisfaction is as relevant as the other PROMs (Ring and Leopold 2015). Hamilton et al. (2017) reported that patient satisfaction does not correlate well with HRQoL scores, complications or radiographic parameters. Passias et al. (2016) observed that revisions after ASD surgery did not affect patient satisfaction and Hart et al. (2017) that stiffness after pan-lumbar fusion had no impact on functional status or satisfaction with the treatment although these factors are expected to have an impact on the outcome of surgery. Conversely, Eskilsson et al. (2017) found high patient satisfaction and HRQoL scores after PSO surgery for ASD and poorer HRQoL and satisfaction in patients who had flatback after previous low back fusion surgery. Patient expectations and relationship with the surgeon may be more important factors in satisfaction with the treatment than the actual anatomical and clinical outcome.

ASD patients are frailer and have several co-morbidities compared to patients operated on due to short segment lumbar spondylolisthesis or spinal stenosis only (Yagi et al. 2018). The best radiographic and clinical outcome (PRO) is achieved when the whole deformity is meticulously analysed before the correction strategy (Schwab et al. 2012, Yilgor et al. 2017a), most suitable surgical method (Berjano and Lamartina 2014) and length of fusion are chosen (Sciubba et al. 2015a) and the risk for the individual is properly evaluated (Yoshida et al. 2017, Miller et al. 2018, Pellise et al. 2018). The use of a written informed consent with respect to the choice of treatment method helps patients to recall the risks and benefits of ASD surgery (Mauffrey et al. 2008).

Summary

Recognizing spinal deformity, associated symptoms and disability from the heterogenous group of back pain patients is a key to successful treatment of this complex disease. Diagnostics comprise comprehensive imaging and clinical examination of the patient. The imaging protocol includes MRI of the affected and symptomatic segment of spine, a full spine standing radiograph with a standardized technique and additional bending x-rays to evaluate the rigidity of the deformity.

Measuring the results of ASD treatment includes not only follow-up data with imaging and a clinical examination but also patient-reported outcome. To obtain valid, reliable and feasible PRO data, the instruments used must be chosen to suit the population and the disease in question. A combination of generic, general spine and disease-specific PRO instruments are usually included in the follow-up of ASD treatment. Despite the risks and possible complications, carefully chosen patients with disabling symptoms related to severe deformity benefit from surgical correction of ASD.

3 AIMS OF THE STUDY

The aims of this study were as follows:

I to evaluate the intra- and interrater reliability of sagittal spinopelvic parameters from digital full spine plain radiographs measured with basic software tools by readers with different experience in an unselected adult population with degenerative spinal disorders

II to evaluate the reliability and validity of the Finnish version of the Scoliosis Research Society (SRS) questionnaire and score version 30 among adult patients with degenerative spinal disorders

III to study the occurrence of sagittal malalignment, the applicability of a simplified grading of the sagittal modifiers of the Scoliosis Research Society-Schwab adult spinal deformity classification, and the deformity-specific SRS questionnaire version 30 in an unselected adult cohort with symptomatic degenerative spinal disorders

IV to study the permanence of radiographic correction, mechanical complications, predictive factors for poor patient-reported outcomes, and patient satisfaction after surgical correction of adult spinal deformity

4 PATIENTS AND METHODS

This doctoral dissertation consists of four separate studies conducted in the Central Hospital of Central Finland, Jyväskylä between the years 2012 and 2017. The hospital is the only tertiary spine centre serving an adult population of 232 000 (2017).

4.1 Study population

The prevalence of adult spinal deformities in the Finnish population is not known. Recognition of a spinal deformity requires taking a radiograph, which exposes the subject to small dose of irradiation. To study prevalence in a whole population sample without intention to treat is not ethically justifiable. Thus, the study utilised symptomatic patients referred to the Jyväskylä Central Hospital spine clinic owing to prolonged degenerative thoracolumbar spinal disorders according to the hospital consultation guidelines. A second cohort of patients had undergone surgical correction of a spinal deformity in Jyväskylä Central Hospital between 2007 and 2016. **Table 10.** Patient selection in all four studies, with inclusions and exclusions, is described in **Figure 23.**

Table 10. Outline of patients in Studies I-IV.

Study	Patients	Number	Gender and age
Study I Reliability of Spinopelvic Measurements	Patients at the outpatient clinic	n=49	17 males 32 females Mean age 54(SD 15) years
Study II Finnish SRS-30 validity and reliability	Patients at the outpatient clinic	n = 274	111 males 163 females Mean age 61(SD 13) years
Study III Sagittal deformity in degenerative spine	Patients at the outpatient clinic	n = 637	279 males 358 females Mean age 55(SD 15) years
Study IV Outcomes of adult spinal deformity surgery	Spinal deformity surgery patients	n = 79	22 males 57 females Mean age 64(SD 10) years

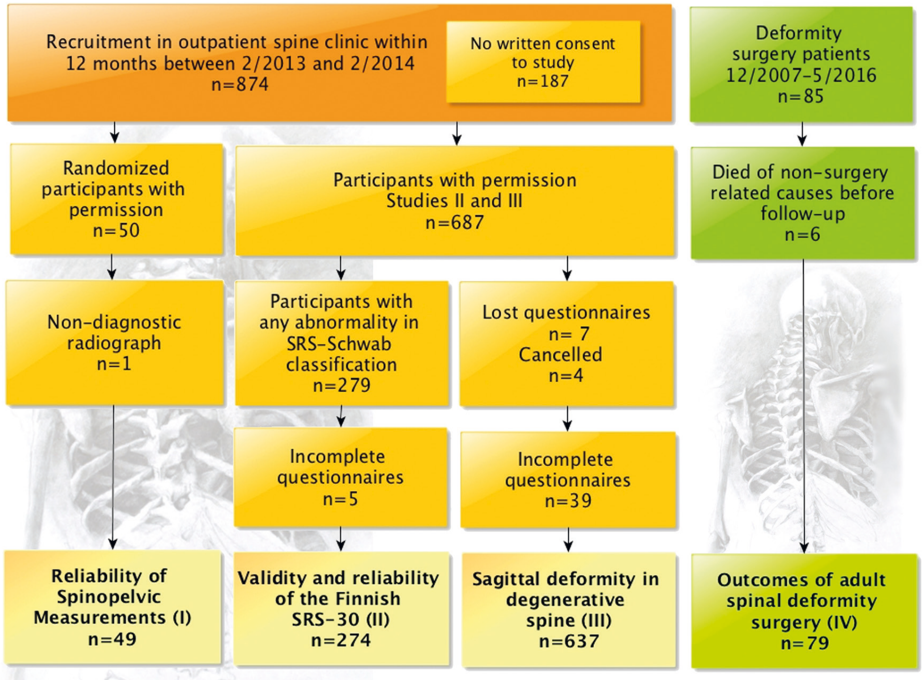


Figure 23. Flowchart for patient inclusion in analysis of Studies I-IV.

4.2 Patients

Study I *Reliability of Spinopelvic Measurements*. The reliability and repeatability study of radiographic spinopelvic measurements was studied with 49 patients attending the outpatient clinic of the Department of Physical Medicine and Rehabilitation or Spine Orthopaedics in Jyväskylä Central Hospital. The inclusion criteria were minimum age 18 years, prolonged degenerative thoracolumbar disease with or without radiculating symptoms, eligible full spine digital radiographs and written consent to participate in the study.

Study II *Validity and reliability of the Finnish SRS-30*. The study on the linguistic and cultural adaptation of the SRS-30 questionnaire was conducted among 247 adult patients with a thoracolumbar problem who had been referred to the outpatient clinic of the Department of Physical Medicine and Rehabilitation or Spine Orthopaedics in Jyväskylä Central Hospital. The inclusion criteria were minimum age 18 years, prolonged degenerative thoracolumbar disease with or without radiculating symptoms, ability to communicate in the Finnish language and written consent to participate in the study. The exclusion criteria were pregnancy, malignancy, acute trauma or symptoms. The patients who had + grades in any of their radiographic spinopelvic sagittal modifiers of the SRS-Schwab adult spinal deformity classification (SVA, PT or PI minus LL) were enrolled (**Table 4**).

Study III *Sagittal deformity in degenerative spine*. A total of 637 patients were included in the study of the sagittal deformity in degenerative spine. The patients had been referred between January 2013 and January 2014 to the outpatient clinic of the Department of Physical Medicine and Rehabilitation or Spine Orthopaedics in Jyväskylä Central Hospital. The inclusion criteria were minimum age 18 years, prolonged degenerative thoracolumbar disease with or without radiculating symptoms, ability to communicate in the Finnish language and written consent to participate in the study. The exclusion criteria were pregnancy, malignancy, acute trauma and acute symptoms.

Study IV *Outcomes of adult spinal deformity surgery*. The spinal deformity surgery study was conducted with 79 patients who had been operated in the Jyväskylä Central hospital. The inclusion criteria were age > 18 years and correction of sagittal and/or coronal deformity as the main surgical procedure.

4.3 Study design

For the *Reliability of Spinopelvic Measurements* study (I) a statistical power calculation (Walter et al. 1998) (Power 0.80, alpha level 0.05, acceptable ICC > 0.75 and maximum loss of patients 5%) posited a minimum of 44 radiographs. 49 consecutive participants' full spine digital radiographs were read independently by three raters. One was an experienced spine surgeon, the second an experienced radiologist and the third a resident orthopaedic surgeon. The second rating of the same radiographs was performed in random order after a minimum interval of two weeks. Three study questions were set:

1. Is the quality of full spine radiograph images and the capability of the basic software measurement tools adequate for good reliability and repeatability of measurements of the spinopelvic parameters?

2. Do individual parameters differ in reliability and repeatability?

3. Do raters differ in reliability and repeatability?

In the *Finnish SRS-30 validity and reliability* study (II), participants answered the first questionnaire package on arrival at the imaging and outpatient clinic. The first questionnaire package included the translated and culturally adapted version of the Finnish SRS-30, ODI version 2.0, the VAS for back and leg pain, RAND-36, DEPS depression scale and various health-related and socio-demographic items. The second package was mailed and answered 2 weeks after the first questionnaire. The second package included the SRS-30 and a question on whether the participant's back symptoms had been stable or become better or worse in the interval between the questionnaires. The study hypothesized that the translation from American English to Finnish and the cultural adaptation of the SRS-30 questionnaire had linguistic and psychometric validity among adult patients with degenerative spinal disorders.

The data for the *Sagittal deformity in degenerative spine* study (III) was collected from outpatient clinic participants who filled in the validated Finnish SRS-30, ODI version 2.0, the VAS for back and leg pain, RAND-36, and DEPS depression scale and answered the health-related and socio-demographic questions. An anterior-posterior (ap) and lateral view full spine radiograph was obtained. A simplified scoring procedure was created from the SRS-Schwab ASD classification and patients were divided into three grades of deformity severity: none or mild, moderate and marked. The study proposed that:

1. A consecutive non-selected adult outpatient cohort with prolonged symptomatic degenerative spinal conditions will include different grades of sagittal and coronal deformities.

2. The SRS-Schwab adult spinal deformity classification can be simplified to include only sagittal modifiers, which can be reduced to three categories of deformity severity without losing the HRQoL matching the original classification.

3. The SRS-30 will be able to detect the different grades of spinal deformity and the concomitant disability as well as the ODI.

The *Outcomes of adult spinal deformity surgery* study (IV) comprised a retrospective review of the medical records and full spine radiographs of 79 patients who had received corrective surgery for a spinal deformity. The patients were identified from the hospital electronic database using the ICD-10 classification of diseases and the National Institute for Health and Welfare (THL) classification of surgical procedure codes. The diagnosis contained all the M41 subgroups. The procedural codes used for screening are shown in **Table 11.** The ODI, the VAS and the SRS-30 scores included in the patient records were utilized in the study. The available preoperative, immediate postoperative, 3-month and 1-, 2-, 3- and 5- year postoperative full spine radiographs were included in the study. The study questions were:

1. Does the radiographic result of spinal deformity correction remain significantly better 5 years postoperatively than at the preoperative baseline?

2. Can individual patient-related preoperative predictive factors for poor patient-reported outcomes be identified?

3. What is the complication rate in the study population?

4. Is patient satisfaction with the surgery related to radiographic correction, lack of complications and clinical outcome with PROMs?

Table 11. The NOMESCO procedure codes used for Study IV.

Procedure code	Interpretation
NAK30	Osteotomy of the spine
NAK10	Partial resection of a vertebra
NAG65	Combined lumbar anterior and posterior fusion
NAG60	Anterior lumbar fusion with fixation
NAG63	Posterior lumbar fusion, more than 3 vertebrae
NAG72	Reconstruction of a vertebra
NAG57	Combined thoracic spine fusion anterior and posterior

NOMESCO The Nordic Medico-Statistical Committee

4.4 Radiographic evaluation

Full spine radiographs were acquired using the manufacturer's Auto Image Paste application. Initially, 2–3 separate sub-exposures were taken depending on the patient's height. Sub-images were processed and aligned automatically into a single composite image using the overlapping anatomical content of the sub-images. The effective dosage simulated with PCXMC software (Radiation and Nuclear Safety Authority STUK) for the full spine radiograph was 0.14 mSv for an adult male weighing 70-80 kg in lateral view and 0.22 mSv for the preferred anterior-posterior view in imaging adult patients. The Workstation IDS7 (Sectra AB, Sweden) picture archiving and communication system (PACS) software, version 14.3 was used to perform the measurements from the digital images.

The spinopelvic radiographic parameters for Study I were selected after a review of the literature to find the measurements with the lowest intra-interrater reliability and repeatability (Aubin et al. 2011). Lateral view angular parameters, including TK, PT, PI, SS, and the interval parameter SVA, were chosen to determine the accuracy of different modes of measurement (**Figure 11**).

In Study II, the measurements of the SRS-Schwab ASD classification sagittal modifiers from lateral view radiographs were used to select the participants for the validation of the deformity-specific SRS-30 questionnaire. The participants received the second set of questionnaires if any of the sagittal modifiers (PT, PI-LL, SVA) was ≠ 0 (**Table 4**).

In Study III, the SRS-Schwab sagittal modifiers were measured from full spine radiographs: PI-LL, sagittal vertical axis (SVA), and PT (**Figure 11**). The spinopelvic parameters of the participants were classified according to these measurements and a new simplified classification to depict the deformity severity in adults was created. The SRS-Schwab classification 0 scored 0 points, + scored 1 and ++ 2 points (**Table 12**).

Table 12. The simplified SRS-Schwab ASD classification sagittal modifier scoring.

Score	Deformity severity
0-1 points	None or mild deformity
2-3 points	Moderate deformity
4-6 points	Marked deformity

0=zero points, + = 1 point, ++ = 2 points

In Study IV the full spine radiographs of the deformity surgery patients were obtained from the PACS archive. The sets of radiographs included preoperative, immediate postoperative, 3-month and 1-, 2-, 3- and 5-year postoperative control radiographs. Not all patients had the full set, a factor that was taken into consideration in the biostatistic analysis. The parameters measured from the radiographs included PI, LL, PT, SVA, TPA, TK and T1-slope from the lateral view and the Cobb curves from the AP view (**Figure 11**).

4.5 Patient reported outcomes

Selection of the PRO instrument was based on a review of the literature on spinal deformity treatment. The criteria were that the instrument is well established in the study of degenerative spinal conditions and has been validated in the Finnish language and culture (**Table 13**).

Table 13. The PRO instruments used in the analyses of Studies I-IV.

	ODI	VAS	RAND-36	DEPS	SRS-30	FIT-index
Study I	+	+	+	+	+	
Study II	+	+	+	+	+	
Study III	+	+			+	+
Study IV	+	+			+	

PRO Patient reported outcome, ODI Oswestry Disability Index, VAS Visual Analog Scale, RAND Research And Development Corporation, DEPS depression scale, SRS Scoliosis Research Society, FIT (Frequency Intensity Time) index of Kasari

4.5.1 The Scoliosis Research Society Questionnaire version 30

The Scoliosis Research Society has established the deformity-specific HRQoL questionnaire in several versions (22, 22r, 23, 24 and 30) available free of charge on the society's webpage: www.srs.org. None of these have previously been published and validated in Finnish. The study target was the surgical treatment of adult deformity. Thus, the SRS-30 was selected for translation and cultural adaptation in the validation study (II). The Scoliosis Research Society was contacted and approval to use their instrument in the validation study was obtained from the copyright holder. The SRS-30 comprises 23 preoperative and 7 postoperative questions. Questions 21 and 22 are applicable to both conservative and operative treatment, since they ask about satisfaction with or willingness to have the same management again in the same situation. 5 response alternatives follow each question, except for post-surgery questions 25, 26, 27, 28, and 30, which only have 3. Questions with 5 alternatives score 1-5 points (worst to best), and those with 3 alternatives 1, 3, or 5 points. On the score sheet, the questions are grouped into five domains: Function/Activity, Pain, Self-image/Appearance, Mental Health and Satisfaction with management. Subtotal scores excluding satisfaction with treatment management and a total score comprising all questions can be calculated separately. The questions in the mental health domain have been adopted, with permission, from the SF-36. A domain, excluding the domain Satisfaction with management, which has two pre- and one postoperative question, is scored if at least three of the five questions are answered.

4.5.2 Other patient-reported outcome measures

The ODI (Fairbank and Pynsent 2000) is a self-administered and validated questionnaire. The Finnish-validated ODI 2.0 (Pekkanen et al. 2011) was used to capture back-specific disability.

The RAND-36 is a generic HRQoL questionnaire comprising 8 dimensions: physical functioning, role-physical, bodily pain, general health, vitality, social functioning, role-emotional, and mental health (Hays and Morales 2001). A Finnish-validated version of the RAND-36 was used.

Back and leg pain were separately assessed with a 100-mm cline (0 mm, no pain; 100 mm, worst possible pain) (Price et al 1983).

The DEPS depression scale (Poutanen et al. 2010) contains 10 items, each scored from 0 to 3 points (0, "not at all"; 3, "very much"). The threshold value for 50% of the patients having depression is 12 points, and the probability of depression increases as the total score increases.

The Frequency Intensity Time (FIT) index developed by Kasari (Hayward and Stolarczyk 1996) asks about the frequency, type and duration of exercise per week. Scores range from 1 to 100 points indicating low (<36), moderate (36-63) or high (>63) physical activity levels.

4.5.3 General health information

All participants in Studies II-III filled in a general health information questionnaire. The questionnaire data includes height, weight, marital, educational and occupational status, smoking, daily exercise, need and description of pain medication (**Appendix 1**). The patients in Study IV filled in the preoperative data sheet, which includes the aforementioned data.

4.6 Validation of the Scoliosis Research Society Questionnaire version 30 (SRS-30)

To conduct the validation study of the SRS-30 among patients with degenerative spinal disorders, two independent forward translations were made from English to Finnish by health-care professionals. Both translators were bilingual, with Finnish as their first language. They produced a written report and highlighted phrases and cultural features that could be misinterpreted or have more than 1 potential translation. A consensus on the two translations, resulting in version one, was reached by the translators after a discussion of the discrepancies between their translations.

A bilingual translator for whom English was the first language and who had no health-care background performed a back-translation. This was done to ensure that the content of the translated version remained the same as that of the English-language original. Differences between the translation into Finnish and the back-translation were then analysed to ensure that the linguistic and cultural content of the Finnish translation matched that of the original. A professional linguist from the Finnish Medical Association (Duodecim) crosschecked the Finnish language version against the original English version and the back-translation and made a written report on the findings. An expert committee composed of two translators and two experts in the English and Finnish languages produced the final consensus version of the SRS-30 questionnaire.

This final consensus version was pilot-tested following the guidelines by Beaton et al. (2000) and Wild et al. (2005) with 20 Finnish-speaking individuals with low-back pain. The test group filled in the questionnaire and gave noted in writing any offensive content or difficulty encountered in answering or understanding the questions. The expert committee evaluated each step of the translation procedure in detail and the integrity of the questionnaire as a totality. The final Finnish version (**Appendix 2**) was introduced along with a report on its construction.

4.7 Statistical analysis

In Studies I-IV, the characteristics of the study population were expressed with 95% confidence intervals as means with standard deviations (SD), medians with inter-quartile range (IOR) of minimum-maximum for continuous variables, or as counts with percentages for categorical variables.

In study I, the intraclass correlation coefficients (ICCs) were used to examine intra- and inter-rater reliability. Coefficients with 95% confidence intervals (95% CI) were determined using a one-way random single measurement for the intra-rater analysis and a two-way mixed model with absolute agreement for inter-rater analysis (Shrout and Fleiss 1979). Reliability was regarded as acceptable if the ICC was >0.75 (Portney and Watkins 2015). The standard error of measurement (SEM) was used as a parameter of absolute reliability and agreement. In the intra-rater analysis, *i.e.* one-way analysis of variance (ANOVA) with the patient as a random factor, the SEM was calculated as the square root of residual variance. The CIs for the SEM were obtained by using the degrees of freedom associated with estimated residual variance and the percentage points from the corresponding chi-square distribution analysis (Milliken and Johnson 2009). For the inter-rater analysis, the SEM was defined as the square root of the sum of the residual and rater variances to explore any systematic differences between raters (deVet at al. 2006). CIs were calculated from the asymptotic covariance matrix of variance components obtained by using the restricted maximum likelihood method and the general Satterthwaite approximation for the degrees of freedom (Milliken and Johnson 2009).

The coefficient of repeatability (CR) and the smallest detectable change (SDC) were obtained by multiplying the corresponding SEM by 1.96 and the square root of 2, respectively. The SDC is the minimum difference between 2 readings, which must be exceeded to demonstrate a true significant change.

Kappa and Fleiss-κ coefficients with bootstrapped 95% CIs were also calculated for classified measures. Kappa values for alignment were defined as follows: slight, 0.00–0.20; fair, 0.21–0.40; moderate, 0.41–0.60; substantial, 0.61–0.80; and almost perfect, 0.8–1.00 (Landis and Koch 1977). A paired sample t-test was performed to detect possible systematic bias in the intra-rater analysis. For the inter-rater analysis, ANOVA for repeated measurements, using Scheffe's correction for pairwise comparisons, was adapted to determine systematic differences between raters. Limits of agreement according to Bland and Altman (1986) were generated to illustrate absolute reliability with a mean difference of ±1 SD.

In Study II, internal consistency was estimated by calculating the Cronbach's α with bootstrapped 95% CIs. A self-reported change in symptoms within a 2-week interval was recorded, and patients with stable or unstable symptoms were analysed separately. The intraclass correlation (ICC) was measured using a 2-way mixed model with absolute agreement. Reproducibility, i.e. test-retest reliability under different conditions, was estimated by using intraclass correlation (ICC) and standard error of measurement (SEM). Standard error of measurement (SEM) was defined as the square root of the sum of the residual variance and the variance in measurements from the corresponding 2-way mixed model (deVet et al. 2006).

Confidence intervals for SEM were calculated using the asymptotic covariance matrix of variance components obtained using the restricted maximum likelihood method and general Satterthwaite approximation for degrees of freedom (Milliken and Johnson 2009). Correlation coefficients with bootstrapped CIs were calculated by the Spearman method (Dawson and Trapp 2004). Differences between groups were tested by independent samples *t* test or analysis of variance.

In Study III, statistical significance for the hypothesis of linearity across the modifier grades and deformity classes was evaluated using analysis of variance, the Cuzick test, and the Cochran-Armitage test. In the case of violation of the assumptions (e.g. non-normality), a bootstrap-type test was used. No adjustment for multiplicity was made. The α-level was set at $p < 0.05$ and all analyses were performed using STATA 14.0 (StataCorp LP, College Station, TX, USA).

In Study IV, the statistical comparison between the groups was performed with a t-test, permutation test, chi-square test, or the Fisher-Freeman-Halton test when appropriate. Repeated measures for radiographic parameters were analysed using generalising estimating equation models with an unstructured correlation structure. Kaplan-Meier curves were used to illustrate information on the cumulative risk for reoperation. The 95% confidence bands for the Kaplan-Meier estimate were calculated using the bootstrap method. Multivariate logistic regression was used to estimate odds ratios (OR) and 95% CIs for poor outcomes. Correlation coefficients were calculated with the Pearson method. Stata 15.0 (StataCorp LP, College Station, TX, USA) was used for analysis.

4.8 Ethical considerations

The study protocol was approved by the Research Ethics Committee of the Central Finland Health Care District. Permission to conduct the study was provided by the Chief Medical Director of Jyväskylä Central Hospital.

In accordance with the principles of the Declaration of Helsinki (World Medical Association 2013), an informed written consent was obtained from all participants. Patients were informed that they could withdraw from the study at any time without any impact on their medical care. The study participants were all Finnish-speaking patients, and all written information was in Finnish.

Participants were given an ID number for research purposes throughout the study. During the analyses, the patients were unidentifiable and decoding identities was possible only for the principal investigator, who was also responsible for the participant register.

5 RESULTS

5.1 General results of Studies I-IV

All patients were adults aged 18-88 years. The patients in Studies I-II were subpopulations of the patients in Study III (**Figure 23**). The descriptive data on the study populations are presented in **Table 14** and **Table 15**. Age showed a poor correlation with the SRS-30 Subscore (R^2=0.010) and the ODI total score (R^2=0.047); however, in both instruments a tendency was observed towards better scores in the younger and lower scores in the older age groups (**Figure 24**).

5.2 Study I Reliability of Spinopelvic Measurements

Intra-rater measurement

Paired sample t-test revealed no statistically significant differences between both readings, indicating that no systematic intra-rater bias was present. The intra-rater CR values indicated that Rater 1's standard error of measurement (SEM) values were systematically lower than those of the other two raters (Original publication I, Table 2). The intra-rater difference for all three raters in the PI measurements is presented in **Figure 25**. For SS, PT, PI, and TK the variation in the intra-rater ICC scores was 0.82–0.99, whereas the variation for the SEM values was 0.8–4.9°. For the SVA, the ICC was 0.99 and for SEM the variation was 2.2–5.8 mm. A tendency towards bias between the two PI measurements (p=0.001, linear regression analysis) was observed depending on the magnitude of the measured value. The other sagittal modifiers of the SRS-Schwab ASD classification, PT (p=0.530) and SVA (p=0.061), were similarly measured independent of the magnitude of the value and the difference between the majority of the measurements of PT and SVA varied between ±2° and ±5 mm, respectively.

Inter-rater measurement

When comparing the inter-rater results, some systematic bias was observed in the measurements of angles ($p < 0.05$); for Rater 1, the measured absolute angles were systematically higher than those of the other raters (Table 1, original publication I). The maximum mean difference in angular measurements between the three raters varied from 2 to 5° for reading 1 and from 1 to 4° for reading 2.

The inter-rater ICC scores for the measured variables varied from 0.78 to 0.99 (Table 3 original publication I). The SEM values varied from 2.5° to 6.2° for SS, PT, PI, and TK depending on the measured angle, and reading round. For SVA, the SEM was ~5 mm. The SDC varied from 7° to 17° for all the measured angles and was ~13 mm for SVA.

Table 14. Descriptive data of the study populations of Studies I-IV. Percentages calculated from valid answers of each item. Data presented in mean(SD) and in age and BMI also with minimum and maximum.

	Study I	Study II	Study III	Study IV
Participants	49	274	637	79
Age	54.0 (15.2) 18 - 87	61.0(13.0) 23-88	54.8(15.3) 18-88	64.3 (10.3) 22-79
Female	32 (65.3)	163 (59.5)	358 (56.2)	57 (72.2)
BMI	27.5 (4.2) 20–36	27.9(4.7) 18-43	27.6(4.8) 18-45	27.0 (4.4) 18-42
Marriage/common law marriage	31(67.4)	187(68.2)	452(70.8)	NA
Years of education	12(3.7)	12(3.7)	12(3.6)	NA
Available for work	30(65.2)	114(41.6)	379(59.4)	NA
Smokers	12(26.1)	61(22.3)	153(24.0)	NA
Physical activity (Kasari-FIT-index)	39.2(22.4)	30.0(8.7)	33.5(21.8)	NA
Daily users of painkillers	22(44.9)	146(53.3)	338(53.1)	NA
Duration of current back pain in months, median (IQR)	24(7,120)	24(7,72)	18(7,60)	NA
Diagnosis group				
Back pain	27(55)	72 (26)	198(31.1)	79(100)
Nerve root entrapment	14(29)	130 (47)	307(48.2)	44(55.7)§
Spondylolisthesis	NA	48(18)	98(15.4)	} 79 (100)‡
Structural deformity*	8(16)	24(9)	34(5.3)	
Deformity severity				
None or mild	21(42.9)	92(33.6)	407(63.9)	14(17.7)
Moderate	22(44.9)	125(45.6)	159(25.0)	16(20.3)
Marked	6(12.2)	57(20.8)	71(11.1)	49(62.0)

BMI Body Mass Index
FIT-index Frequency Intensity Time index
IQR interquartile range
NA data not available
* Scoliosis, kyphosis, post-fracture deformity
§ Concomitant spinal stenosis requiring surgery with the deformity
‡ Complex deformities including kyphosis, scoliosis and spondylolistheses

Table 15. Patient reported outcome measures of the participants in Studies I-IV. The scores are pre-treatment ones in studies I-III. In study IV the ODI and VAS scores are pre-treatment and the SRS-30 scores post-surgery results.

	Study I	**Study II**	**Study III**	**Study IV**
Participants	49	274	637	79
ODI	35(18) 6–80	40(15) 4-74	39(16) 2-89	51 (12) 24-80†
VAS back pain	61(24) 10-97	60(28) 0-100	59(28) 0-100	72 (22) 0-100†
VAS leg pain	52(28) 0-98	55(31) 0-100	54(31) 0-100	64 (28) 0-100†
DEPS	7.8(6.0)	9.6(6.4)	9.2(6.6)	NA
SRS-30 domains				
Function/Activity	3.00(0.75)	2.75(0.70)	2.82(0.75)	2.96(0.90)◊
Pain	2.50(0-72)	2.45(0.75)	2.40(0.76)	3.41(0.88)◊
Self Image/ Appearance	2.90(0.72)	2.77(0.65)	2.86(0.67)	3.14(0.80)◊
Mental health	3.57(0.90)	3.41(0.89)	3.41(0.88)	3.46(0.92)◊
Subtotal score	2.99(0.62)	2.85(0.59)	2.88(0.61)	3.25(0.75)◊
Satisfaction with Management	3.27(0.91)	3.09(0.72)	3.12(0.75)	3.59(1.07)◊
Total score	3.00(0.58) 1.91-4.22	2.89(0.60) 1.35-4.17	2.88(0.56) 1.41-4.26	3.26(0.75) 1.38-4.93
RAND-36 scales				
Function	47.9(28.0)	38.8(23.2)	43.9(24.3)	NA
RoPhy	21.7(35.6)	12.7(26.7)	16.1(29.0)	NA
RoEm	51.4(44.8)	43.3(44.2)	48.4(43.8)	NA
Energy	50.8(22.4)	48.0(23.4)	47.5(23.3)	NA
Mental	65.7(22.0)	65.7(22.3)	64.7(21.9)	NA
SocFunc	65.2(27.1)	55.9(28.5)	57.3(28.7)	NA
Pain	29.2(20.4)	28.1(18.4)	28.5(19.7)	NA
GeHealth	49.8(18.1)	44.0(19.4)	46.2(19.4)	NA

ODI Oswestry Disability Index 2.0 Finnish version
VAS Visual Analogue Scale
DEPS Depression Scale
SRS-30 Scoliosis Research Society questionnaire version 30
NA data not available
† Preoperative values, ◊ Postoperative values
Abbreviations of RAND-36 dimensions: Function indicates physical functioning; RoPhy, role limitations due to physical health; RoEm, role limitations due to emotional problems; Energy, energy/fatigue; Mental, emotional well-being; SocFunc, social functioning; GeHealth, general health.

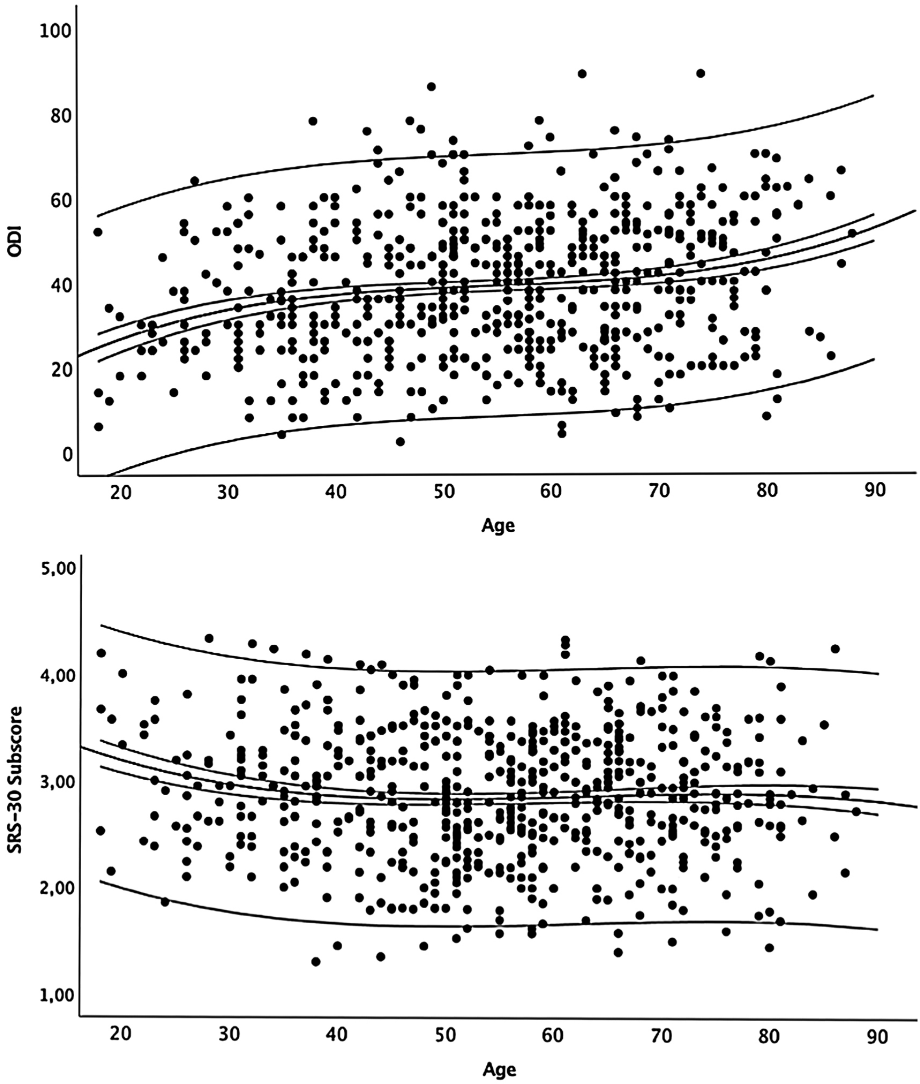


Figure 24. Distribution of the ODI total and SRS-30 subscores of symptomatic patients with spinal degenerative disorders by age. The best fit was obtained with a cubic-spline curve. Means and 95% confidence intervals are depicted

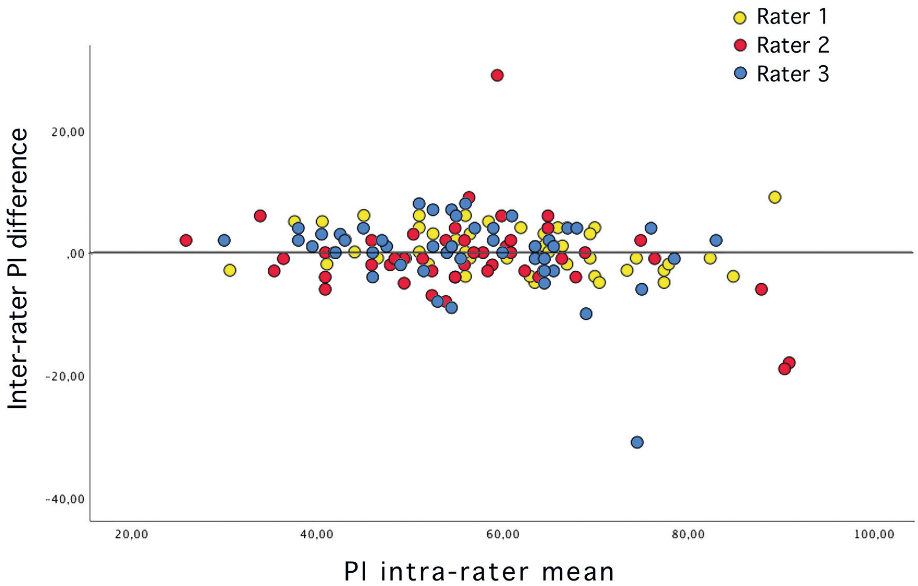


Figure 25. Bland-Altman plot shows the difference between the two readings for the pelvic incidence (PI) measurements for all three raters.

Fleiss-κ values (95% CI) among the 3 raters for the classified parameters were as follows: SVA reading 1, 0.94 (0.80–1.00); SVA reading 2, 0.97 (0.86–1.00); PT reading 1, 0.83 (0.70–0.93); and PT reading 2, 0.81 (0.68–0.91). For SVA, the raters assigned the same classification grade in 96% and 98% of cases in the first and second reading rounds, respectively. For PT, the corresponding figures were 86% and 84%. The ability to place the same patients in the same category in both reading rounds varied between raters. Rater 1 placed the individual SVA and PT values in the same SRS-Schwab class in both readings (κ = 1). Readers 2 and 3 placed a few patients into different classes in the second reading round. For SVA and PT, Rater 2's intrarater κ values were 1 and 0.89 (95% CI: 0.71 – 0.96), and Rater 3's κ values 0.88 (95% CI: 0.72 – 1.00) and 0.89 (95% CI: 0.75 – 0.97), respectively.

5.3 Study II Validity and reliability of the Finnish SRS-30

The translation process

Forward-backward translation was used to produce the Finnish version of the SRS-30. The translation process was generally straightforward; however, semantic issues were debated in the translation of questions 11 and 18. It was agreed that Finns know the generic names of pain medication better than the trade names, and hence the original formulation of question 11 was altered after negotiation. Speculation on Question 18 occurred during the translation process. After deliberation, a consensus was reached that the phrase "Do you go out…" represents social activity more than a specific date.

Reliability and reproducibility study

A statistically significant difference was observed between the moderate and marked deformity groups in the SRS-30 domains of function/activity (mean±SD: moderate, 2.80±0.71; marked, 2.56±0.63; p=0.022) and self-image/appearance (mean±SD: moderate, 2.82±0.65; marked, 2.58±0.61; p=0.016).

Patients were divided into non-surgery (n=255, 93%) and earlier spine surgery (n=19, 7%) groups. Symptoms remained stable in 57.7%, worsened in 23.7%, and improved in 18.6% of the patients in their answers to the 2nd set of SRS-30 questionnaires. The Cronbach α for internal consistency of the SRS-30 domains varied between 0.635 (pain) and 0.919 (mental health) in the non-operative and 0.635 (function) and 0.880 (mental health) postoperative cohorts' subscores. The internal consistency of the domain Satisfaction with management was lower in the non-operative than postoperative group (**Figure 26**). No floor or ceiling effect was found in any of the SRS-30 domains.

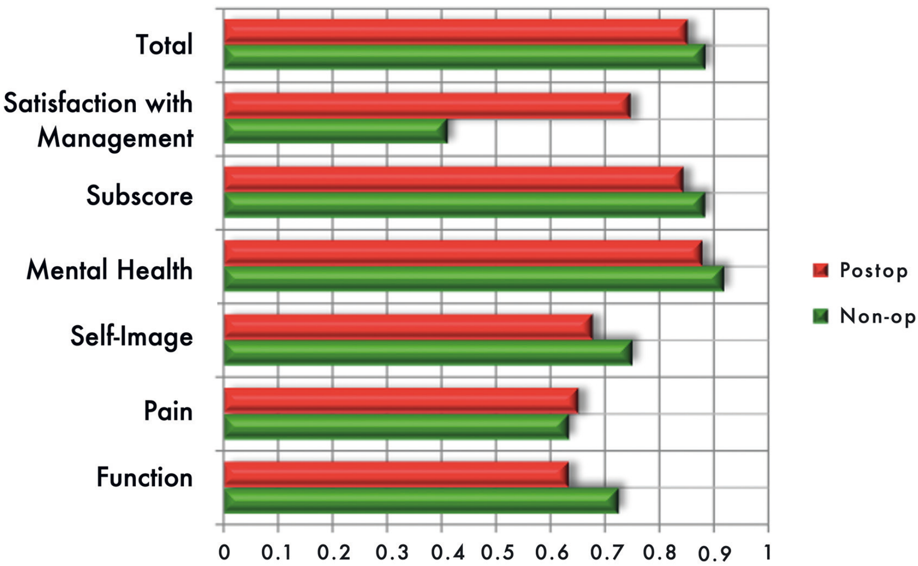


Figure 26. The internal consistency of the SRS-30 domains expressed as Cronbach's alpha (0-1) in non-operative (n=255) and postoperative (n=19) cohorts. For domain means, floor and ceiling effects and 95% confidence intervals, see original publication II, Table 2.

The reproducibility of the domains was measured in relation to change in symptoms during the 2-week interval between answering the 1st and 2nd SRS-30 questionnaires (**Table 16**). The best ICC-values in each domain except Satisfaction with management were found in patients whose symptoms remained stable, while the SRS-30 proved capable of detecting change in clinical status even after a short interval.

The correlation of the SRS-30 domains was tested separately against the dimensions of the RAND-30 (physical functioning, role of limitations due to physical health, role of limitations due to emotional problems, energy/fatigue, emotional well-being, social functioning and general health), the ODI 2.0 score, DEPS and VAS leg and back pain scales. The highest Spearman correlation coefficient (r=0.90) was found between the SRS-30 and RAND-36 mental health scores. The function domain showed best correlation coefficient with the ODI 2.0 (r=-0.69), pain domain with the RAND-36 pain dimension (r=0.54) and self-image domain with DEPS (r =-0.71). For all the correlation coefficients, see original publication II, Table 4. The function, self-image, and mental health domains correlated moderately or strongly, but pain correlated weakly with the RAND-36, ODI, DEPS, and VAS pain scales. The subtotal and total score correlations with the VAS pain scales were good, but satisfaction with management correlated poorly with all the instruments.

5.4 Study III Sagittal deformity in degenerative spine

Age, body mass index (BMI), duration of symptoms, and use of painkillers increased significantly while physical activity, working, and educational status decreased significantly with deformity severity (**Table 17**). The lowest percentage of 0 grades (57%) was detected for PT, while the proportions for SVA and PI-LL were 65% and 71%, respectively (**Figure 27**). The paramount cause of disability measured by the ODI was SVA <9.5 cm (++) (p=0.002) (**Figure 28**). The simplified SRS-Schwab sagittal deformity severity groups showed significantly different ODI 2.0 (p=0.033), SRS-30 Function (p=0.004) and self-image/appearance (p= 0.030) domain scores. No significant differences between the sagittal deformity severity groups were observed for pain intensity or frequency, mental health or satisfaction with management.

Table 16. Reproducibility of the SRS-30 Questionnaire and self-reported change in symptoms measured after the 2-week interval. All patients (n=274 patients; improved, n=51; stable, n=158; worse, n=65) filled in all the domains required for a subscore; 253 patients (improved, n=47; stable, n=146; worse, n=60) also answered the satisfaction with management domain and hence had a total score.

Domains	Patients self-reported change	First measurement mean (SD)	Change at measurement 2, mean (95% CI)	ICC (95% CI)	SEM (range)
Function	All	2.75 (0.70)	-0.02 (-0.07 to 0.03)	0.829 (0.788 to 0.863)	0.28 (0.26 to 0.31)
	Improved	2.93 (0.71)	0.12 (-0.02 to 0.26)	0.719 (0.555 to 0.829)	0.37 (0.31 to 0.46)
	Stable	2.79 (0.72)	-0.04 (-0.09 to 0.02)	0.871 (0.827 to 0.904)	0.25 (0.22 to 0.28)
	Worse	2.51 (0.59)	-0.08 (-0.18 to 0.02)	0.754 (0.627 to 0.843)	0.29 (0.24 to 0.35)
Pain	All	2.45 (0.75)	0.08 (0.01 to 0.14)	0.741 (0.681 to 0.790)	0.38 (0.35 to 0.42)
	Improved	2.52 (0.66)	0.27 (0.12 to 0.41)	0.636 (0.384 to 0.789)	0.42 (0.32 to 0.61)
	Stable	2.54 (0.78)	0.05 (-0.03 to 0.13)	0.759 (0.684 to 0.818)	0.38 (0.34 to 0.42)
	Worse	2.19 (0.68)	-0.01 (-0.13 to 0.12)	0.708 (0.561 to 0.811)	0.36 (0.31 to 0.43)
Self-image/ appearance	All	2.77 (0.65)	0.00 (-0.05 to 0.05)	0.795 (0.749 to 0.834)	0.30 (0.28 to 0.33)
	Improved	2.90 (0.59)	0.19 (0.06 to 0.31)	0.722 (0.528 to 0.839)	0.34 (0.27 to 0.46)
	Stable	2.82 (0.65)	-0.02 (-0.07 to 0.04)	0.856 (0.808 to 0.893)	0.24 (0.22 to 0.27)
	Worse	2.54 (0.64)	-0.09 (-0.22 to 0.04)	0.653 (0.489 to 0.772)	0.38 (0.32 to 0.46)
Mental health	All	3.41 (0.89)	-0.10 (-0.19 to -0.01)	0.703 (0.637 to 0.758)	0.53 (0.49 to 0.58)
	Improved	3.61 (0.80)	0.18 (-0.20 to 0.56)	0.371 (0.110 to 0.585)	0.96 (0.80 to 1.19)
	Stable	3.47 (0.89)	-0.12 (-0.19 to 0.04)	0.847 (0.790 to 0.888)	0.34 (0.30 to 0.39)
	Worse	3.09 (0.89)	-0.27 (-0.41 to -0.14)	0.764 (0.573 to 0.866)	0.43 (0.33 to 0.62)
Subscore	All	2.85 (0.59)	-0.01 (-0.05 to 0.03)	0.843 (0.805 to 0.874)	0.24 (0.22 to 0.26)
	Improved	2.99 (0.51)	0.19 (0.05 to 0.34)	0.611 (0.393 to 0.762)	0.38 (0.31 to 0.51)
	Stable	2.91 (0.61)	-0.03 (-0.07 to 0.01)	0.904 (0.871 to 0.929)	0.18 (0.17 to 0.21)
	Worse	2.59 (0.52)	-0.12 (-0.19 to -0.05)	0.832 (0.710 to 0.901)	0.21 (0.17 to 0.29)
Satisfaction with management	All	3.10 (0.71)	0.25 (0.16 to 0.35)	0.463 (0.338 to 0.568)	0.56 (0.48 to 0.67)
	Improved	3.23 (0.70)	0.49 (0.26 to 0.73)	0.314 (0.028 to 0.552)	0.66 (0.47 to 1.11)
	Stable	3.11 (0.65)	0.24 (0.13 to 0.35)	0.475 (0.322 to 0.601)	0.50 (0.43 to 0.62)
	Worse	2.98 (0.82)	0.11 (-0.11 to 0.33)	0.504 (0.289 to 0.670)	0.59 (0.50 to 0.72)
Total	All	2.87 (0.55)	0.00 (-0.03 to 0.04)	0.874 (0.842 to 0.901)	0.20 (0.18 to 0.22)
	Improved	3.01 (0.48)	0.19 (0.09 to 0.29)	0.726 (0.458 to 0.857)	0.27 (0.19 to 0.43)
	Stable	2.94 (0.57)	-0.02 (-0.06 to 0.02)	0.905 (0.870 to 0.930)	0.17 (0.15 to 0.19)
	Worse	2.60 (0.50)	-0.09 (-0.16 to -0.02)	0.840 (0.737 to 0.904)	0.20 (0.17 to 0.26)

Table 17. Characteristics of the study cohort classified with the simplified Scoliosis Research Society-Schwab adult spine deformity classification of sagittal modifiers. Data presented in percentages, mean(SD) or interquartile range (IQR)

Characteristic	**Sagittal deformity severity group**			
Total n=637	**Mild or none** n= 407	**Moderate** n=159	**Marked** n=71	p-value
Female	222 (54)	87 (55)	49 (69)	0.066
Age (years)	51 (15)	59 (13)	66 (13)	<0.001*
BMI (kg/m^2)	27.1 (4.9)	28.1 (4.5)	29.1 (5.0)	<0.001*
Marriage or common-law marriage	305 (75)	109 (69)	37 (52)	<0.001*
Years of education	13 (4)	11 (4)	11 (3)	<0.001*
Available for work	283 (70)	81 (51)	14 (20)	0.001*
Smokers	101 (25)	39 (24)	12 (17)	0.23
Physical activity (Kasari FIT-index)	35 (22)	33 (22)	22 (18)	0.001*
Daily use of painkillers	207 (51)	83 (52)	49 (69)	0.016*
Back pain VAS	58 (29)	62 (27)	60 (29)	0.69
Leg pain VAS	53 (31)	56 (33)	59 (29)	0.14
Duration of current back pain in months, median (IQR)	18 (6,48)	25 (10,68)	24 (9,102)	0.002*
Diagnoses				
Scoliosis	9 (2)	12 (8)	13 (18)	<0.001*
Spondylolisthesis	57 (14)	35 (22)	6 (9)	0.91
Neural compression	201 (49)	69 (43)	37 (52)	0.81
Degenerative spine	140 (34)	43 (27)	15 (21)	0.01*
Previous spine surgery	19 (5)	8 (5)	7 (10)	0.095

FIT Frequency Intensity Time
BMI Body Mass Index
VAS Visual Analogue Scale

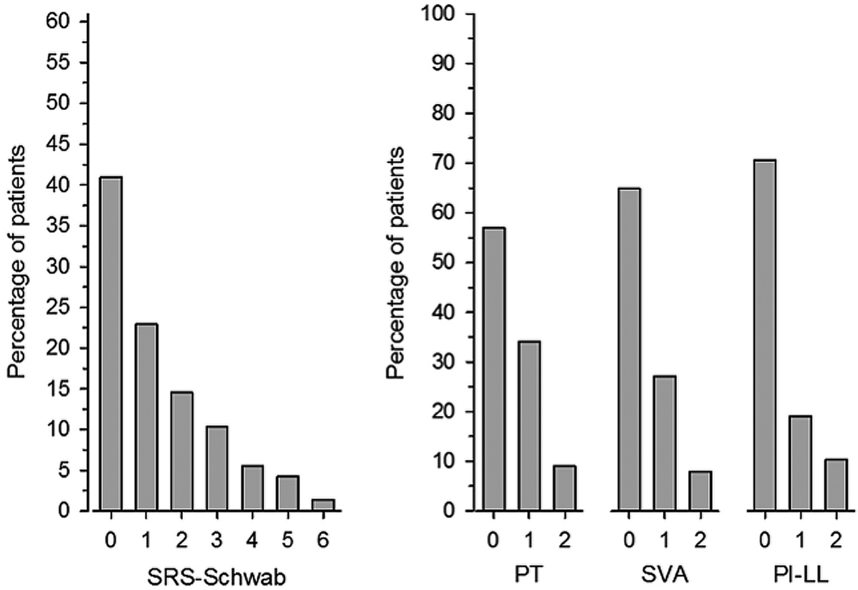
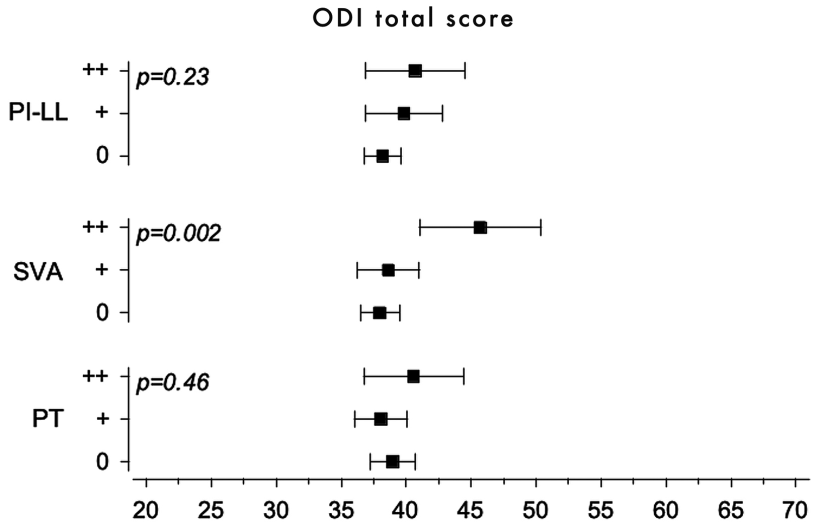


Figure 27. Distribution of patients according to sagittal deformity severity with the original sagittal modifier grades and the modified grades. Deformity severity groups: mild or no deformity (0 or 1+ modifiers), moderate (2-3+ modifiers), and marked (4-6+ modifiers). SRS, Scoliosis Research Society; PI-LL, pelvic incidence-lumbar lordosis; PT, pelvic tilt; SVA, sagittal vertical axis; ODI, Oswestry Disability Index



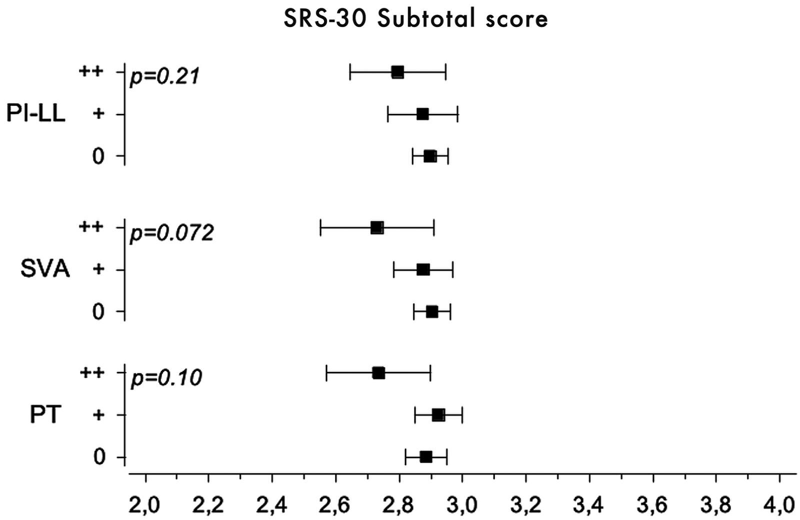


Figure 28. Individual sagittal modifiers in relation to the Oswestry Disability Index total and Scoliosis Research Society questionnaire 30 subtotal scores. Severity: 0 mild or none, + moderate, ++ marked. PI-LL, pelvic incidence-lumbar lordosis; PT, pelvic tilt; SVA, sagittal vertical axis; ODI, Oswestry Disability Index.

5.5 Study IV Outcomes of adult spinal deformity surgery

Preoperative data

The Study IV patient baseline data are presented in **Table 14** and **Table 15.** These patients all had sagittal, coronal or complex deformities due to different aetiologies with or without spinal canal stenosis and accompanying compression of neural elements. 29 (36.7%) patients had no co-morbidities, 25 (31.6%) had one and the remainder had two to four medical conditions that are classified as risk factors in ASD surgery. The preoperative data are described in **Table 18.**

Table 18. Preoperative diagnoses and co-morbidities of the patients operated for ASD.

Main deformity diagnosis	**n (%)**
Sagittal deformity	21(26.6)
Degenerative scoliosis	37(46.8)
AIS + degeneration	6(7,6)
Neuromuscular disease	15(19.0)
Posttraumatic deformity	4(5.1)
High-grade spondylolisthesis	1(1.3)
Spinal stenosis	44(55.7)
Previous fusion	28(35.4)
Comorbidities	
Diabetes	13(16.5)
Rheumatoid arthritis	9(11.4)
Chronic respiratory disease	8(10.1)
Osteoporosis	15(19.0)
Neuromuscular disease	15(19.0)
Depression	17(21.5)
Neuropathic pain	15(19.0)
≥ 2 comorbidities	24(30.4)

Postoperative data

The main methods of surgical correction, fused levels, blood loss and adverse effects of surgery are presented in **Table 19**. The ODI score decreased from 51 (12) to 34 (20), the VAS back pain score from 72 (22) to 29 (26), and the leg pain score from 64 (28) to 35 (30) mm, and all three scores were significantly better ($p=0.001$) at follow-up than at preoperative baseline. Of the 15 (19%) patients with a postoperative motor deficit, 10 were reversible, 4 irreversible, and 1 had a thoracic spinal cord infarct and paraparesis during the postoperative night. All the patients with an irreversible neural injury recovered ambulatory function despite the deficit.

Radiographic sagittal parameters TPA, PT, TK, and PI-LL improved with surgery and the improvement was maintained at the 4-5 year follow-ups ($p\leq 0.001$). T1S increased minimally after the first postoperative year, but after 3 years the decline in the angular parameter compared to the baseline value was significantly greater ($p<0.001$) (**Figure 29)**. Twelve patients had >10° added PJK and 5 had added lordosis without failure of the bone or implant or spinal stenosis at the proximal junction during the follow-up compared to the immediate postoperative radiograph. None of the patients had implant- or bone-related complications at the distal junction of fusion.

Risk for the first reoperation due to mechanical failure of instrumentation or bone was highest within the first year at 13.9% (95% CI 8.0 to 23.7%), increasing to 29.8% (19.4 to 43.9%) during the 5-year follow-up (**Figure 30).**

Rod breakage was associated with the use of chromium cobalt (CrCo) in 2-rod constructs ($p=0.003$) and higher number of fused levels ($p=0.004$). Proximal junctional failure (PJF) was correlated with osteoporosis ($p=0.018$). The severity of deformity, amount of correction, and other co-morbidities were not significantly different between patients with and those without mechanical complications.

According to the SRS-30 results, 49 (62.0%) patients were satisfied or very satisfied with the treatment and 57 (72.1%) would have the same operation again; 15 (19.0%) were neither satisfied nor dissatisfied and 11(13.9%) were unsure about repeating the same operation. Of the radiological parameters, only insufficient SVA correction and residual sagittal malalignment correlated with patient satisfaction ($p=0.027$). In all the other radiographic parameters, the amount of correction did not affect patient satisfaction.

The SRS-30 total score was 3.28 (0.76). The best score in the SRS-30 domains at follow-up was in Satisfaction with management, at 3.59 (1.10), and the worst was in Function, at 2.97 (0.91). At follow-up, the ODI and SRS-30 total scores correlated well $r= -0.78$ (95% CI -0.86 to -0.68, $p<0.001$); the patients satisfied with management had the best scores in both instruments and vice versa (**Figure 31**). The predictive indicators for membership of the poorest 20th percentile in the ODI and/or SRS-30 total scores were male sex and depression (**Table 20**).

Table 19. The methods of spinal correction, peri- and postoperative complications and reoperations after adult spinal deformity (ASD) in Study IV.

Deformity correction	
Posterior column osteotomy †	10 (12.7 %)
Osteotomy (3CO)	39 (49.4 %)
ALIF + posterolateral fusion	30 (38,0 %)
Estimated blood loss (ml)	2175 (2047)
Fused levels, mean (SD); min-max	8.8 (3.8) 2-17
Complications	
Dural lesion	22 (27.8%)
Deep wound infection*	7 (8.9%)
Postoperative haematoma*	4 (5.1%)
Pulmonary embolism	6 (7.5%)
Neural injury	15(19.0%)
Rod breakage*	10(12.7%)
Proximal junction failure*	8 (10.1%)
Implant-related failure*	1 (1.3%)
New stenosis in ASD correction*	1 (1.3%)
Reoperated patients‡	26 (32.9%)
Unscheduled readmissions < 3 months	13(16.5%)

† Includes Ponte and Smith-Petersen osteotomies

3CO three-column osteotomy

ALIF Anterior Lumbar Interbody Fusion

SD standard deviation

* Required surgical treatment

‡5 patients had more than 1 reoperation

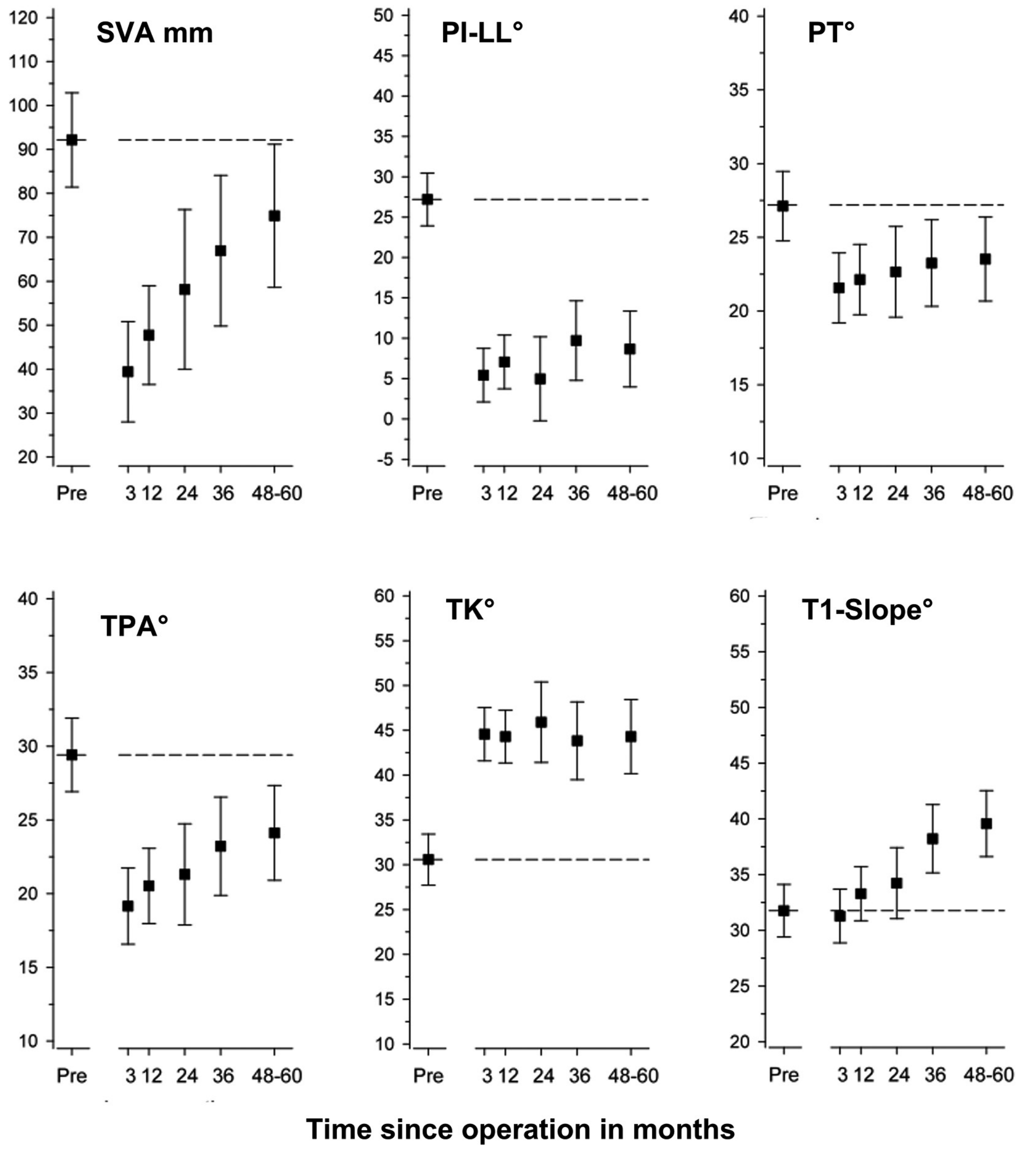


Figure 29. Effect of deformity correction surgery on spinopelvic parameters evaluated from full spine radiographs at 3, 12, 24, 36 and 48-60 months after surgery.

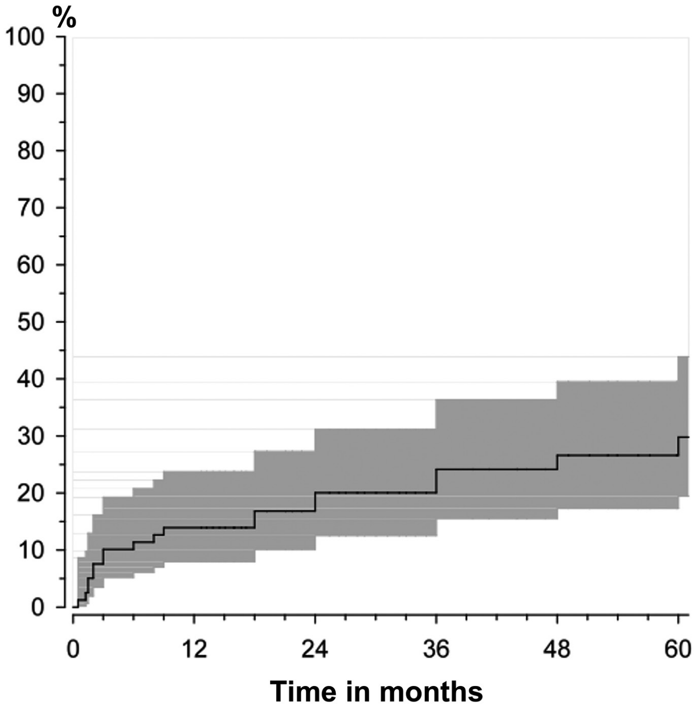


Figure 30. Probability (95% confidence interval) of first reoperation after discharge from primary surgery. At 1 year: 13.9% (8.0 to 23.7%); cumulative probability at 5 years: 29.8% (19.4 to 43.9%).

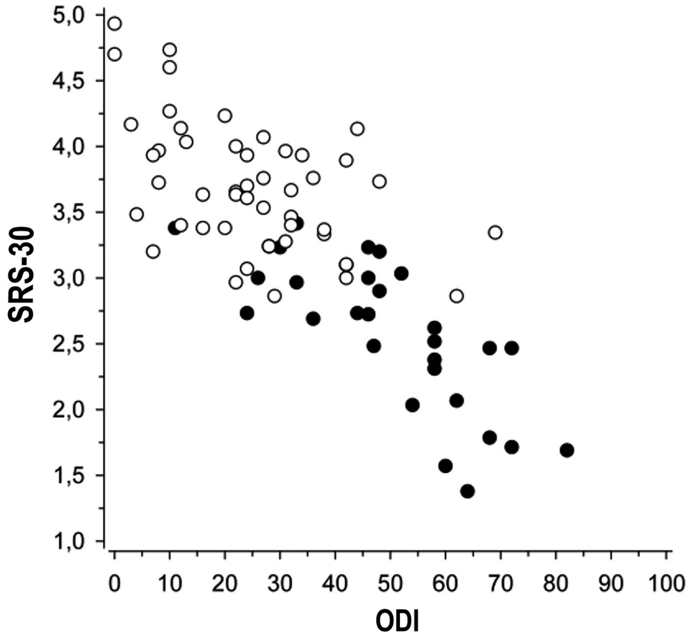


Figure 31. Correlation of SRS-30 and ODI total scores (r=-0.78 (-0.86 to -0.68) p<0.001) with distribution of patients satisfied (white dot) or dissatisfied (black dot) with spine management.

Table 20. Predictive parameters for poor outcomes: patients in the worst 20th percentile of scores in the SRS-30 and/or ODI.

Variable	OR (95% CI)	p-value (Linearity)
BMI at operation	0.88 (0.73 to 1.06)	0.169
Male	9.66 (1.41 to 66.30)	0.021*
Age at operation	1.11 (1.00 to 1.23)	0.059
PI-LL preoperatively	0.99 (0.93 to 1.03)	0.349
Previous fusion	0.88 (0.72 to 1.06)	0.815
SRS-Schwab sagittal deformity severity		0.59
1	1 (Reference)	
Moderate 2-3	1.51 (0.13 to 18.10)	
Severe 4-6	2.08 (0.14 to 30.77)	
Depression	6.97 (1.39 to 34.87)	0.018*
Rheumatoid arthritis	0.62 (0.06 to 6.55)	0.688
Diabetes	2.41 (0.46 to 12.61)	0.299
Neuropathic pain	2.22 (0.43 to 11.57)	0.335
Osteoporosis	1.85 (0.35 to 9.77)	0.470
Chronic respiratory disease	2.56 (0.28 to 23.65)	0.409
Deformity diagnosis		0.85
1 Scoliosis	1 (Reference)	
2 Degenerative, loss of sagittal alignment	1.47 (0.29 to 7.39)	
3 Neuromuscular	1.74 (0.21 to 14.50)	

OR = Odds ratio
ODI = Oswestry disability index
SRS = Scoliosis Research Society
CI = confidence interval
BMI = body mass index
PI-LL = pelvic incidence minus lumbar lordosis

6 DISCUSSION

6.1 General discussion

The leading global cause of disability in 2015 worldwide was lower back and neck pain (GBD 2015 Disease and Injury Incidence and Prevalence Collaborators 2016). In Finland back pain has become slightly more common on the 21st century, especially in age cohort 30-54 years and the cost of sick leave and disability pensions alone due to spinal diseases was almost 500 million euro in 2012 (Low back pain: Current Care Guidelines Abstract, 2017).

The cost-effectiveness of spinal care, both conservative and surgical, is difficult to estimate due to diversity in interpretations of indications and treatment methods (Pohjolainen et al. 2007, Kepler et al 2012). Although the direct costs of spinal surgery and related medication in Finland were only 5% of the total costs of musculoskeletal related diseases in Finland (Pohjolainen et al. 2007), the amount of degenerative spinal surgery is predicted to rise in all western societies (Fehlings et al. 2015). In the USA, the volume of spinal fusion surgeries has increased by over 60% within the last ten years. This increase is especially evident in the elderly population and in the numbers of patients with spondylolistheses or scoliosis (Martin et al. 2018). The indications and choices of surgical techniques continue to depend on the surgeon's personal preference rather than on scientifically established evidence. This unfortunate practice can lead to surgical complications or maltreatment (Försth et al. 2016 and Fisher et al. 2012). Thus, methods supporting proper technical planning and monitoring PROMs are essential in controlling both HRQoL and the direct and indirect costs of spinal surgery.

Imaging is the key method for assessing musculoskeletal disorders. Optimal imaging methods cover both morpohological and functional impairments and protect the patient from unnecessary harm. Based on these statements, Galbusera et al. (2016) recommend that comprehensive evaluation of the entire spinopelvic alignment should always be performed when planning degenerative spinal surgery. Limiting imaging to a single motion segment or short regions of the spine should be considered clinically inadequate (**Figure 32**). Full spine radiographs are essential in analysing spinal alignment and the compensatory mechanisms that were found activated by the degenerative disease process in the present studies. Standardised patient positioning and image processing provide reliable images (Marks et al. 2009) but each surgeon or radiologist should also be aware of the pitfalls in performing radiographic measurements and of the reliability and repeatability of one's own readings, which also vary with experience in the field. Training, incorporating basic software tools or semiautomatic planning programs, increases reliability and repeatability and reduces inter-measurement error (Lafage et al. 2015). The present research shows that the existing basic imaging protocols can provide reliable and repeatable measurements when the measurement technique is adequate.

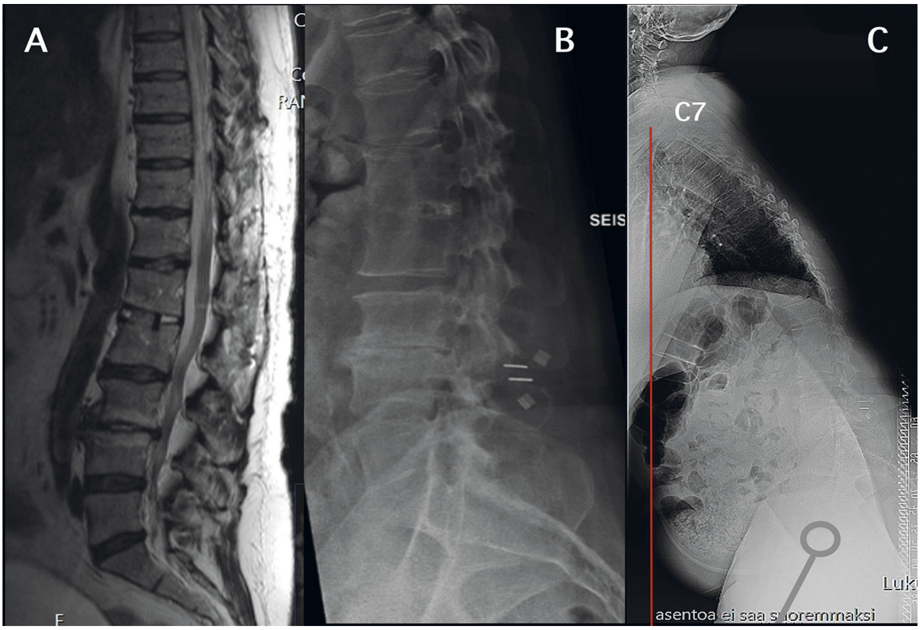


Figure 32. Diagnostic imaging of a spinal disorder by supine MRI, standing lumbar radiograph and standing full spine radiograph of the same patient. The radiographs were obtained during the same day in separate institutions and the MRI one month earlier during the same disease episode. Information obtained from a single imaging modality is limited and thus a comprehensive diagnosis of spine-related problems is not achieved from a single image.

Accurate evaluation of the surgical outcome requires the use of radiographic, surgical and patient-reported outcome measures. Surgical classifications such as the SRS-Schwab ASD classification (Schwab et al. 2102) help in categorizing and comparing clinical outcomes. The advantage of a clinical classification is simplicity with good coverage of the clinical problem. The simplified version with sagittal modifiers of the SRS-Schwab ASD classification proved capable of separating different grades of deformity severity without loss of significant information. The Schwab classification combines radiographic and PROM data and refers the threshold values of the radiographic modifiers to the SF-36, ODI and the SRS-questionnaire scores (Schwab et al. 2010 and 2012).

The use of valid, disease-specific, culturally and psychometrically adapted PROMs is of paramount importance. In measuring disability related to low back conditions, the ODI is widely used and well validated. However, in adults and adolescents with spinal deformities the ODI can be insufficient to cover the more complex 3D changes of the whole spine. The SRS-30 is the latest version of the series of SRS questionnaires and includes extra questions for post-surgery patients. Spinal fusion surgery for adults requires evaluation of the whole deformity and compensatory mechanisms (Galbusera et al. 2016 and LeHuec et al. 2015b) using both radiographic and PRO measures. The Finnish SRS-30 translation proved reliable and valid among Finnish-speaking patients treated for pain and disability associated with adult spine deformities. It includes two domains that are not covered by other generally used questionnaires but are important in defining HRQoL in relation to the patient's spinal deformity and its treatment.

Le Huec et al. (2011a) emphasise the importance of correcting the deformity of each spinal segment when performing fusion surgery. The SRS-Schwab ASD classification modifiers can be used in determining degenerative spinal deformities and the surgery can then be targeted to correct the 3D deformation. Severe disability and pain drive patients to seek surgical treatment for degenerative spinal problems. For surgery to provide better HRQoL for patients, a thorough evaluation of the relevant radiographic, medical and psychological factors combined with a risk-benefit analysis is needed (Miller et al. 2018). The complication rates continue to be higher than in low back fusion surgery (Sciubba et al. 2015). The baseline disability and pain scores were higher among the operated ASD patients in our study compared to the unselected patient cohort with any prolonged spinal disease. Both the ODI and VAS scores showed significant improvement, and the SRS-30 questionnaire tested for the first time on Finnish adult ASD patients correlated well with the ODI and with patient satisfaction with management. Technical solutions exist for the two typical mechanical complications, i.e. rod breakage and proximal junctional failure (PJF), but neither of them has been definitively solved. In rigid and complex deformities, the risk of preoperative neural deficit also remains a notable complication and cause of postoperative disability. The surgeon must then balance between the tolerance of the neural tissue and the precision of the anatomical correction since malalignment after surgery increases the risk for reoperations and poor HRQoL. With appropriate patient selection, adult deformity surgery can achieve good outcomes. In our Finnish, operated ASD patient cohort, depression predicted poor PRO independently of gender or surgical or radiographic result. The majority of the ASD patients were satisfied with the surgery and would have the same operation again even if their physical functioning remains low after lengthy spinal fusion.

6.2 Reliability of spinopelvic measurements

Measurement of the spinopelvic radiographic parameters from digital radiographs with basic software tools was reliable and repeatable in both the intra- and inter-rater analysis. Greater experience in performing the radiographic measurements decreases, and greater complexity of the measurement landmarks increases, intra- and inter-rater bias.

The angular measurements that were most difficult to perform appeared to be those of PI and TK, which were comparable with the findings of Aubin et al. (2011). Yamada et al. (2015) analysed the problem of angular measurements and suggested that the difficulty is complexity to identify the sacral endplate precisely. The SDC values for all parameters were higher if the rater was less experienced. Our findings indicated that for complex measurements such as PT and PI, small changes were not detected by less experienced raters during the follow-up imaging, a factor that could significantly impair preoperative planning.

The method for calculating ICC values has not always been reported in detail in previous publications, which renders comparison of ICC values between different populations difficult, and prevents the generalization of findings to a wider range of patients. In addition to ICC values, it is important to calculate SEM values and express variation in the measurement units actually used. It is also important to remember that the smaller the SEM value, the higher the level of agreement.

Kim et al. (2012) compared two radiographic methods used in daily practice: film and digital radiographs. Landmarks were identified manually on film, but on digital radiographs the PACS tool was used. The authors showed that the highest ICC values were achieved with a more experienced rater and with a computerized calculation method. In contrast, the highest variability between two measurements was observed when the rater was less experienced and manual measurements were conducted. Vila-Casademunt et al. (2015) reported ICC values > 0.85 for PI, PT, and SS in patients with lumbopelvic instrumentation. They evaluated 13 raters with different levels of experience and concluded that, after a short tutorial, inexperienced surgeons can reliably measure sagittal pelvic parameters by using a semiautomatic computerized method (Surgimap Spine, Nemaris Inc, New York, NY, USA). In addition, Lafage et al. (2015) published even better reproducibility values with updated measuring software and concluded that enhanced image quality and the new software eliminate differences related to rater experience.

In this study, the SEM values showed some variation, with the most experienced reader showing the smallest intra-rater variability. Vila-Casademunt et al. (2015) found inter-rater SEM values of 4.4° for PI, 2.2° for PT, and 4.2° for SS, all of which resembled our corresponding findings of 5.9–6.2°, 2.5–3.2°, and 4.2–4.3°. Moreover, in a previous study by Aubin et al. (2011), the inter-rater SD units were similar, while in the study by Lafage et al. (2015), ISO (International Organization for Standardization) reproducibility was slightly better than the SEM inter-rater measurements in our study. In both of the above-mentioned studies, the authors concluded that semiautomatic measurement tools offer advantages over manual digital measurements.

For both angular and distance-classified parameter measures, the present κ values were excellent. In an SRS-Schwab adult deformity classification validation study (Schwab et al. 2012), nine raters, authors, and members of the SRS Adult Deformity Classification Committee measured and classified PT and SVA. Their mean κ values for intra-rater reliability were 0.85–1.00 for PT and 0.77–1.00 for SVA, both comparable with our findings, despite the lower experience of the two raters in our study. We suggest that in deformity surgery planning the measured absolute angles and lengths should be also ranked, especially when threshold values are obtained for classified variables. Moreover, the deformity severity class for the threshold values should be considered.

Measurement bias is dependent on extra- and intra-measurement factors. A patient's physical stature, rotated pelvis >30°, obesity, degeneration, osteoporosis, and superimposition of the shoulders can all cause inaccuracy in determining anatomic measurement points (Tyrakowski et al. 2014). Such errors can accumulate when a parameter requires the identification of several anatomical structures. An advantage of using image-processing software is improved identification of landmarks through the application of image enhancement tools. However, the reliability of the measurement remains dependent on rater experience (Aubin et al. 2011 and Vila-Casademunt et al. 2015), as we found in our study.

This study proved that with appropriate investment in image quality and reader training acceptable reliability and repeatability comparable to those of semiautomatic measurement tools can be achieved. Reliable and more comprehensive spinopelvic measurements from digital full spine radiographs can be made with a lower radiation dosage than was possible with lumbar radiographs. This finding encourages implementation of the more reliable method of measuring spinopelvic parameters from full spine radiographs when spinal surgery is planned as a routine practice.

6.3 Finnish SRS-30 validity and reliability

The SRS-30 questionnaire showed linguistic and psychometric validity among adult patients with degenerative spinal disorders. The SRS-30 differs psychometrically from the other PROMs tested (ODI, RAND-36, DEPS, VAS) in questions about pain intensity and duration and has the unique domains of self-image/appearance and satisfaction with management.

Reporting the results of a surgical intervention requires both surgical and PRO measures (Baldus et al. 2011a). No previous linguistic-cultural adaptation and subsequent validation studies of any versions of the SRS questionnaire for use among a Finnish population of adolescents or adults have been published before this study. The first aim of this study was cross-cultural translation, adaptation, and psychometric testing of the Finnish version of the deformity-specific SRS-30 questionnaire among adult (≥ 18 years) patients with any prolonged degenerative spinal disease. The results indicate that the development was successful and that the study group managed to create an applicable questionnaire. The reproducibility and internal consistency of the instrument proved to be good. The translation, cross-cultural adaptation and psychometric testing of the SRS-30 questionnaire were performed following generally approved guidelines (Beaton et al. 2000 and Wild et al. 2005) and the validation data published to allow quality evaluation of the process (Monticone et al. 2010).

According to a recent systematic review, the two most frequently used PROMs in reports on ASD have been the ODI and the SRS-22, which was used in 44% of studies, whereas the SRS-30 appeared in only 7.6% of the eligible adult spinal deformity studies (Faraj et al. 2017). The quantity of clinimetric studies (Marx et al. 1999 and Fava et al. 2012) on PROMs among ASD patients was low. The ODI and the SRS-22 were the most evaluated instruments and their clinimetric properties were found to be the most favourable among ASD patients. Monticone et al. (2010) found that the quality of the linguistic and trans-cultural validation studies of the widely used SRS-22 was mostly poor or moderate and that the validation process was not adequately described. Our research group found no studies on the clinimetric properties of the SRS-30 on adults with spinal conditions of any kind before December 2016 when this study was conducted.

To achieve good reliability and repeatability in clinical and research work, the PRO instrument should be appropriately targeted and sensitive to patients' linguistic and cultural differences. The earlier version, the SRS-22 was found to be a reliable and reproducible instrument among adult degenerative scoliosis patients (Berven et al. 2003) and responsive to surgery on adults (Bridwell et al. 2007). Normative values for SRS-30 scores among adult English-speaking individuals from different states of the USA were published by Baldus et al. (2011b).

As the validation process is laborious and comprises multiple stages, the study group decided on the SRS-30 version of the SRS questionnaires and on investigating degenerative spinal diseases across a wide range from the mildest compensatory changes to severe deformities. The SRS-30 is the most comprehensive version of the SRS questionnaire as it encompasses the earlier versions and also contains specific questions for post-surgery patients. Moreover, the first 23 questions also apply to conservative treatment in both adults and adolescents (Asher et al 2003b). The novel aspects of this study were the first-time validation of the

SRS-30 questionnaire in an unselected adult population with degenerative spinal complaints and the production of a Finnish version of an existing spinal deformity-specific PRO instrument for clinical and research use in a Finnish linguistic and cultural environment.

Discussion by the linguistic and cultural expert committee was needed on only 2 questions, 11 (use of pain medication) and 18 (Do you go out…). The latter question appears in a slightly different formulation in the SRS-22, and this earlier version helped in the cultural interpretation of the question in the SRS-30. This same question was debated by Danielsson and Romberg (2013) when validating the SRS-22r for the Swedish AIS population and had previously also been problematic in the Turkish (Alanay et al. 2005), Spanish (Bago et al. 2004) and Chinese (Cheung et al. 2007) versions. Culture and ethnicity are known to have an influence on SRS questionnaire outcomes in AIS patients. Even within a single culture, the same condition may vary in its manifestations by ethnicity, especially with respect to pain, activity, and appearance (Morse et al. 2012 and Verma et al. 2014). The Finnish pilot test group did not notice patients experiencing any content as offensive or problematic in understanding or answering the questions. The pilot test outcome demonstrated no concerns or reasons to change the content proposed by the expert committee.

The SRS-30 mental health domain questions were drawn from the SF-36 mental health dimension, and a very high reciprocal correlation was both expected and achieved in our study. The function domain correlated strongly with the ODI, which also measures the degree of disability. In the present sample, the mean level of the SRS-30 domains and mean ODI were in line, both indicating severe disability. The moderate correlation in the pain domain may be due to different ways of inquiring about pain: the ODI asks about current status; in this study the VAS asked about pain during the previous week; the SRS asks about pain over the past 6 months and 1 month, and at rest; and the RAND-36 asks about the intensity and inconvenience caused by pain. Self-image is not an item in any of the other comparison questionnaires, but it slightly overlaps with the same areas as the mental health questions; in our study, for example, a strong correlation was found between the SRS self-image domain and the DEPS. Sperduti et al. (2013) found a similar association between a negative self-image and depressive symptoms in healthy young adults with functional MRI of the brain. Satisfaction with management is a domain missing from all the other questionnaires, and thus the correlations were poor.

Compared with the means of the age-sex normative non-scoliotic population data published by Baldus et al. (2011), our symptomatic cohort had significantly lower means in all the SRS-30 domains: from 4.1 to 4.6 vs. 2.46 to 3.11. This suggests that the questionnaire can distinguish a normative non-deformity population from symptomatic adults with any sagittal spine disorders. Baldus and co-workers found that the older the normative age group, the worse their reported SRS-30 subscore means. In the present study with symptomatic individuals, age did not correlate significantly with either the ODI total scores or SRS-30 subscores. This may mean that the relative decrement in HRQoL caused by symptomatic spinal degeneration is greater in younger patients. However, it may indicate that elderly people suffer equally from degenerative deformity as their younger counterparts and do not adapt to the disease as part of normal ageing.

Bess et al. (2009) stated that the disability of adult scoliosis patients cannot be predicted solely by radiographic findings. Our findings parallel these, since only 2 domains, function and self-image, statistically significantly correlated with severity of deformity as measured from radiographs. The fact that ASD comprises of multiple degenerative anatomical changes simultaneously may explain why the SRS-30 domains did not correlate with the anatomical diagnostic groups, i.e. nerve root compression, degenerative disease without known deformity, spondylolisthesis, scoliosis or kyphosis or old fracture.

The internal consistency of the Finnish SRS-30 questionnaire was good in the domains of function and self-image, and in subtotal and total scores, and was excellent in mental health. The total score Cronbach α values were optimal in both the no-surgery and previous surgery groups, since very high values may be evidence of very homogeneous questions (Streiner 2003). The lower internal consistency of the satisfaction with management domain in the non-surgery group may be a result of its comprising only 2 questions, whereas the other domains each contain 5-6 questions. In addition, the internal consistency of our surgery subgroup was higher than has been reported in previous adaptation studies. This result may indicate the good validity of the Finnish SRS-30 in measuring satisfaction with treatment when a recognizable intervention is implemented.

Other authors (Danielsson and Romberg 2013, Bago et al. 2004, Qiu et al. 2011, Haidar et al. 2015) have reported high ceiling percentages in the pain domain of the SRS-22 in adolescents. This was not found in our study on adult patients despite their considerable levels of pain.

Our data showed good or excellent test-retest reproducibility when patients' self-reported symptoms remained stable between questionnaires. When change in symptoms between questionnaires was reported, the lower ICCs indicate that the change was detected during the short 2-week interval. The satisfaction with management domain was the only domain that was less reproducible than the other domains; this result may be due to patients misinterpreting the first consultation without intervention as a treatment modality.

6.4 Sagittal deformity in degenerative spine

This study indicated that sagittal imbalance and compensatory mechanisms are both common and strongly related to deterioration in physical and social functioning outcomes and HRQoL measures in symptomatic adult patients with general degenerative spinal disorders and no pre-known ASD.

Schwab et al. (2005a) found a prevalence of degenerative scoliosis in voluntary patients over 60 years of age and with no history of spine surgery or previously known scoliosis of 68%. This finding indicated that not all coronal de-novo deformities are always symptomatic. Hence, when segmental and local problems appear and surgery is planned on the degenerative spine, the possibility of asymptomatic deformity should be actively explored and, if found, diagnosed as such (Le Huec et al. 2011a and Galbusera et al. 2016). In the USA, Martin et al. (2018) found an increase of over 60% in the volume of spinal fusions during a ten-year period (2004-2015). They concluded that while the prevalence of spinal pathologies is not known, the rate of elective lumbar fusion surgery mostly increased for spondylolisthesis and scoliosis, cases where relatively good evidence exists of its effectiveness. Better diagnoses of spinal deformities in the elderly population and the increased use of fusion surgery to restore spinal alignment may, rather than less effective indications or commercial interests, partially explain this rise in the volume of fusion surgeries (Martin et al. 2018).

One-third of the study population had a moderate or marked sagittal disorder without previously diagnosed spinal deformity. Over one-tenth of patients had marked deformities. The ODI total score deteriorated along with the severity of the deformity. A low baseline physical activity level was related to patients' prolonged pain and dysfunction in all groups. Differences in patient pain levels and socio-demographic background did not explain the linear decline in the FIT index between the deformity severity groups, and hence the authors concluded that the deformity is an independent factor which inhibits physical activity. This finding is important when evaluating the baseline and post-treatment physical activity of deformity surgery patients.

The groups were significantly different in the SRS-30 function/physical activity and self-image/appearance domains. The severity of the deformity did not correlate with self-reported pain or mental health. This may be a result of the variety of aetiologies in our cohort, where the deformity was not the only source of pain and discomfort. However, we found that the duration of pain and the need for painkillers increased with the severity of the deformity, indicating more regular demand for pain medication in patients with severe deformities than in the other groups.

Both the ODI and SRS-30 were sensitive to loss of function. The disease-specific SRS-30 has added value when the deformity is marked, as the other outcome measures do not include items on self-image and appearance. ASD surgery is targeted mostly to the correction of severe deformities, with pain and disability as drivers for surgery (Pizones et al. 2017) The good outcome of ASD surgery is mostly explained by pain relief even if functional levels remain unchanged (Scheer et al. 2015).

The finding that pelvic tilt was the most common modifier indicating sagittal disorders in our study is consistent with previous reports (Le Huec et al. 2011b and Diebo et al 2015b). Increased PT appears before anteriorisation of the SVA (Barrey et al. 2007). Buckland et al. (2016) found that in mild and moderate spinal deformities compensation for neural compression can increase SVA positivity while PT remains normal. In moderate and marked deformities, the desire to maintain an upright position overrides the need for positional neural decompression and thus compensatory mechanisms are activated (Buckland et al. 2016). While this phenomenon of anteriorised SVA and normal PT was seen in a small group of our patients with diagnosed symptomatic neural compression, it was independent of the PI value and not statistically significantly different compared to the non-neural compression groups.

PI-LL mismatch is one of the main drivers of the loss of sagittal alignment (Diebo et al. 20215b). Kim et al. (2014) stated that PI-LL mismatch is associated with pathologic degenerative changes, not the normal aging process. This view is supported by our study on symptomatic patients, as the proportion of PI-LL mismatches increased with the severity of the deformity and disability and was not induced by neural compression-related pain alone.

The range of values of the sagittal modifiers in our study matches those reported by Schwab et al. (2012) in their classification validation study, where cases were selected to represent the known distribution of the grades included in the classification. Schwab et al. (2012) found radiographic parameter thresholds predictive of an ODI score of 40 of 11° for PI-LL, 22° for PT, and 46 mm for SVA. In our study, these values were matched in both the moderate and marked groups, indicating that the classification is valid even in its simplified form with 3 groups of sagittal modifiers. Ours is the first published study to achieve good discriminative ability between deformity severity groups by comparing a simplified version of the validated SRS-Schwab ASD classification with radiographic and PRO measures.

This study indicated that sagittal imbalance and compensatory mechanisms are common and strongly related to deterioration of physical and social functioning outcomes and HRQoL measures in symptomatic adult patients with general degenerative spinal disorders and no pre-known ASD.

6.5 Outcomes of adult spinal deformity surgery

The difference of the radiographic outcome of the corrective surgery for ASD remained significant during the first five years of follow up. The results also show a tendency to loss of sagittal balance in the non-operated areas of the spine and pelvis during follow-up. The risk for reoperation was highest during the first postoperative year and the most typical late complications were related to rod breakage or proximal junctional failure. Patient satisfaction with treatment was related to their ODI and the SRS-30 scores. Depression increased the risk for poor outcome in PROMs even where the radiographic result was acceptable.

The ASD surgery study followed up patients whose main surgical indication was coronal or sagittal deformity and, if needed, neural decompression. The majority of the patients expressed satisfaction with the surgical treatment and would have the same treatment again irrespective of its potentially adverse effects. Our cohort resembled surgically treated patients in previously published studies comparing operative and conservative treatments for ASD (Smith et al. 2016 and Passias et al. 2018). In this study cohort, the correction of spinal alignment remained stable, and patient satisfaction and clinical outcomes were good despite the occurrence of typical deformity surgery-related complications.

In our study population, the indicators of global spinal alignment, i.e., SVA and TPA, showed as significant an outcome as PI-LL, which is the main surgical target for the correction of ASD in the literature (Smith et al. 2016). Whereas PI-LL remained stable, the parameters dependent on sagittal balance, i.e., SVA and TPA, started to deteriorate during the 5-year follow-up. The T1S angle started to deteriorate in parallel with the loss of global alignment, without accompanying changes in TK. PJK explained only a small part of the loss of sagittal balance. Although successful surgical correction did not stop the deterioration of sagittal balance in our patients, the long-term radiographic alignment and clinical outcome (ODI, VAS) remained significantly better than preoperatively. Also the postoperative SRS-30 scores were significantly better than the scores of the matched population with severe deformity at pre-surgery consultation in Study III.

High pelvic retroversion (PT) is a compensation mechanism for lost sagittal alignment and results in hyperextension of the hip joint and loss of natural gait. PT correction in our study was significant, but the mean pre- and postoperative values were both in SRS-Schwab modifier class + (20-30°) of moderate sagittal disorder (Schwab et al. 2012). Moreover, the PT values did not reach the PI-related optimum values of PT=0.37*PI-7 described earlier among asymptomatic patients by Vialle et al. (2005). Kondo et al. (2017) found, in support of our results, that even PT remains high in patients with thoracolumbar fusion to the pelvis they can improve balance and gait when the deformity is adequately corrected.

Mechanical complications related to the first ASD operation appeared after discharge from the hospital. The cumulative probability of reoperation due to mechanical complications in our study was highest during the first postoperative year, and mostly consisted of PJF, followed by rod breakage. Scheer et al. (2013) found similar results, except that their percentages at the 1- and 2-year follow-ups were higher. The known risks factors for PJF are a large degree of correction of coronal curves and sagittal malalignment, long fusion, older age, poor bone mineral density (BMD), previous fusion, and fusion to the pelvis (Yagi et al. 2018). Our study could only confirm a correlation with low BMD, fusion length, and PJF. This may be due to the meticulous planning of surgery and choosing the optimal age- and PI-related method of sagittal correction. In the earlier cases in this study, the method of securing proximal junction was different: transverse process hooks and sublaminar bands instead of vertebroplasty, perforated cemented pedicle screws (Theologis and Burch 2015), and off-label use of teriparatide (Ohtori et al. 2013), all of which may cause bias in our results. The methodological changes were based on technical innovations and evidence from the literature to decrease the risk of PJF and the same bias exists in all very long-term studies since the surgical methods are developing continuously.

The frequency of rod breakage was considerable, especially in 3CO, and led to a change of the operative technique during the follow-up period of the present study material. The two-rod-construct with titanium or CrCo was changed to four hybrid 6.35/5.5-mm titanium (Ti) rods (**Figure 33**). In contrast to our study, Han et al. (24) found that the CrCo material used in ASD fusion to the sacrum was more resistant to rod breakage but increased the amount of PJK. Unlike the 2-rod Ti construct and the amounts and qualities of the materials used in our study, they used multiple CrCo rod constructs. Our study population experienced none of the cage-, bone graft-, bone substitute-, or screw-related complications or reoperations that have been described in other studies (Sciubba et al. 2015 and 2015b and Passias et al 2016).

Patient satisfaction with their surgical management showed a linear correlation with the ODI and SRS-30 total scores, and these PROMs also showed a good reciprocal correlation. Whereas the ODI measures disability in relation to pain, the SRS-30 also asks pre- and postoperative questions on the effect of management on pain, function and activity, mental health, self-image and satisfaction with surgical treatment. The majority of the adult deformity patients considered pain relief the best postoperative change and were satisfied with management, including those whose level of activity or self-image remained unchanged or even decreased after extensive spinal correction and fusion. This is supported by two previous multicentre studies, where a pan-lumbar arthrodesis, irrespective of the proximal fusion end-point, did not reduce patient satisfaction with their functional status

(Hart et al. 2017). Instead, the reduction achieved in pain is the main factor in patient-perceived good outcome (Scheer et al. 2015).

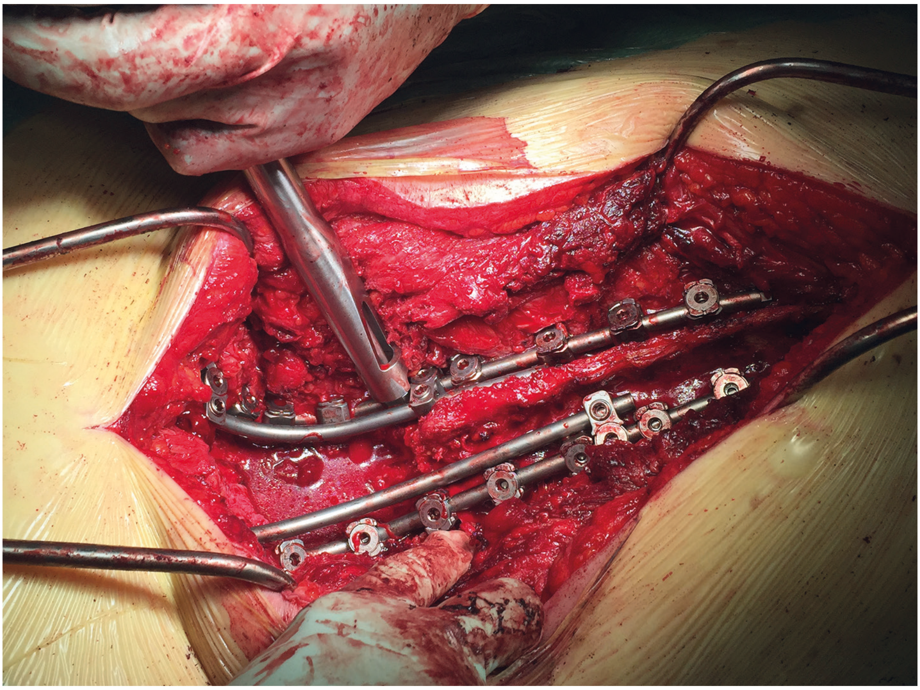


Figure 33. Building the 4-rod construction with titanium rods in the lumbar lordosis area after ASD correction.

Hamilton et al. (2017) found, counter to our results, that patient satisfaction did not correlate with radiographic parameters or complications and correlated only moderately with HRQoL. We tested both absolute radiographic values as well as the amount of individual change in radiographic parameters against patient satisfaction and found no correlation, except with inadequate SVA correction and residual sagittal malalignment. Scheer et al. (2018) reported a correlation between poor radiographic correction of sagittal alignment and worse outcome, and Yamada et al. (2015) found, in line with our results, that patients who achieved good SVA were satisfied (**Figure 34**), even when their LL correction was suboptimal.

When many common risk factors such as advanced age and frailty, ASA risk class ≥4, untreated severe osteoporosis, poor cooperation, BMI > 35, and smoking were excluded in our patient selection, only male sex and depression were found to be risk factors for a poor outcome measured with the ODI and SRS-30. Depression, BMI, and severe baseline back and leg pain were risk factors for poor outcomes in a study by Smith et al. (2013), but no association was found with sex. In our study, baseline disability and pain were similar between the sexes and did not predict poor outcomes in ODI or SRS-30. The male individuals in our cohort were younger and their operative diagnoses consisted mainly of neuromuscular diseases, spondyloptosis, and post-fracture kyphosis, whereas the female individuals predominantly showed degenerative sagittal or coronal deformities. This difference may account for the elevated risk ratio of the male individuals in our surgical cohort. Remarkably none of the seven males with poor PROMs were dissatisfied (SRS-30 question 21) with treatment and six of them would have the same treatment again (SRS-30 question 22).

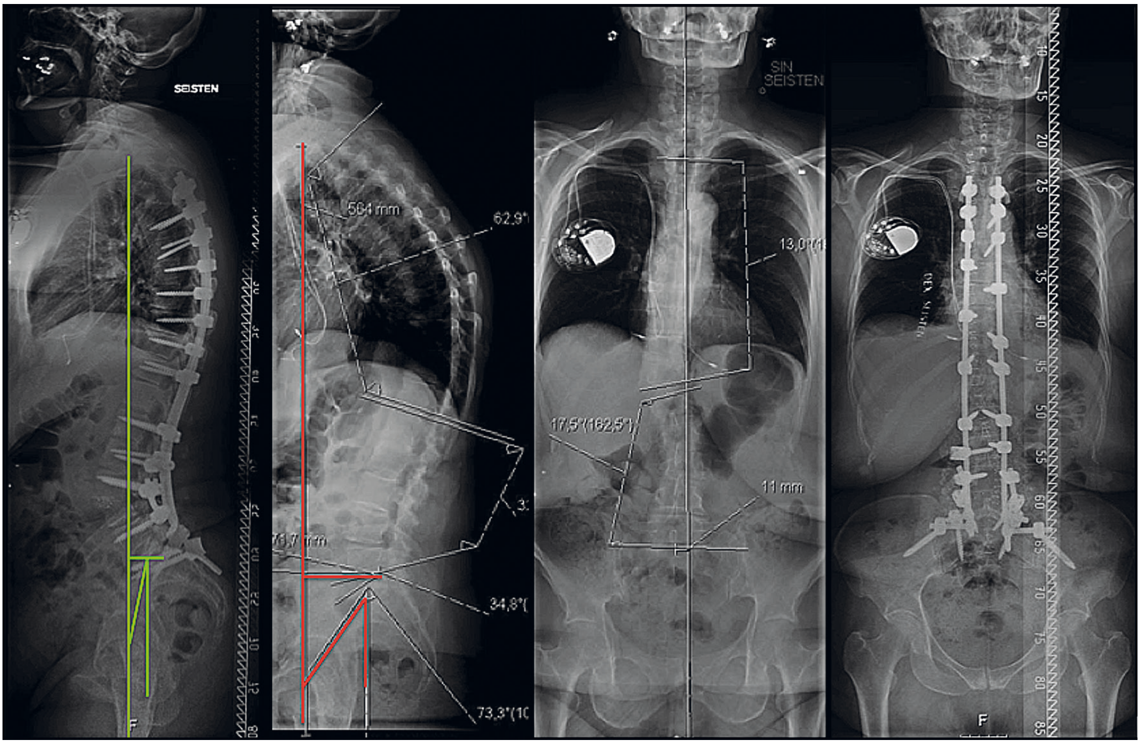


Figure 34. Preoperatively the patient exhibits mild lumbar and compensatory thoracic curves. The main pathology is sagittal: kyphosis, loss of sagittal alignment, high pelvic tilt (PT) and a hyperlordotic cervical spine. The rigid thoracic deformity does not allow compensation. Preoperative images are in the middle and postoperative ones on the lateral sides. Change of SVA and PT indicated in red (preoperative) and green (postoperative) lines in the lateral view images.

6.6 Strengths and weaknesses of the study

The intra- and interrater reliability and repeatability study of spinopelvic measurement has its limitations, including a relatively small sample size despite the statistical power calculation. Moreover, only specific and potentially clinically relevant radiological sagittal parameters were selected instead of analysing all possible parameters. Cervical parameters were not included. The reliability and repeatability of the sagittal parameters, such as LL, were not separately analysed in the selection of very severe coronal deformities. However, since the present consecutive randomly selected sample accurately represented the heterogeneity of patients and image qualities seen in daily clinical practice, the results can be more easily generalized.

To guarantee reliable comparison with the original version, the SRS-30 questionnaire underwent a thorough process of translation and cross-cultural adaptation for use in Finland following the accepted guidelines. Before implementing the validation process of the Finnish version of the SRS-30, the questionnaire was piloted among Finnish-speaking individuals with spinal complaints. The validation process included a comprehensive selection of the PRO instruments used in measuring treatment outcome among adult spinal disease patients.

A weakness of the study is that patients with completely aligned and balanced spine, who had no deformity, or even the slightest signs of compensating for early deformity, were excluded from the validation. Thus, the results found for the SRS-30 cannot be generalized to individuals who are asymptomatic or without deformity. Moreover, the number of post-surgery patients was relatively small.

The strengths of this study are that our institution is the only tertiary spine clinic serving the population in its catchment area and that it operates standardised referral guidelines. While the overall morbidity of the population in the province of Central Finland is around the national average, its values range from the highest to the lowest found across Finland's 19 counties. The study cohort represented the majority of the patients with prolonged degenerative thoracolumbar disorders in the province and therefore the results can be generalized. The weakness remains, however, that to estimate the true prevalence of sagittal deformity would require diagnoses based on radiographs taken from a large cohort of the whole Finnish population, which in turn would involve ethical compromise. Another limitation was that the study was restricted to the sagittal parameters of the SRS-Schwab classification and thus comparison of groups with the other spinopelvic parameters was not possible. On the other hand, the fact that the sagittal parameters are the main factors underlying loss of HRQoL and the prime target for surgical correction means that a simple clinical categorization is a practical method of evaluating the severity of ASD and planning treatment that is available to all physicians. Heterogeneity of the diagnoses and the ASD itself is a weakness in Study IV, although it represents the real world benchmarkable patient cohort as strength of the study (Malmivaara 2015).

To our knowledge, this is the first study to investigate radiological, clinical and PRO factors among consecutive Finnish ASD surgery patients. The strengths of the study were the long-term follow-up, the consecutive patient cohort representing the population of the catchment area and the fact that the patients were selected and operated upon by the same surgical team. The newly translated and validated deformity-specific Finnish version of the SRS questionnaire was tested for the first time in a clinical patient cohort and compared with the more traditional PROMs, i.e. the ODI and VAS. Patient satisfaction with deformity surgery has not been previously published in Finnish ASD surgery patients either.

The limitations of the study were a small population with multiple spinal deformity aetiologies and limited baseline HRQoL measures.

6.7 Clinical implications and future prospects

In the future, it is likely that more newly developed spine-specific calculation and planning tools will be integrated into the baseline software, eliminating the need for separate software, and that better reliability measures will be achieved in repeated studies. Nevertheless, secure, practical and free software tools for pre-surgical analyse of skeletal deformities and the compensatory mechanisms these induce are likely to be widely available in the dicom (Digital Imaging and Communications in Medicine) standard. The key to applying spinopelvic measurements in routine practise is the availability to all spinal surgeons of a high quality standard full spine radiograph. Moreover, the importance of the classical lumbar spine radiograph in diagnostics and treatment has become debatable. On one hand, MRI has surpassed the lumbar radiograph in diagnostic imaging and the radiation dosage to the lumbar area is no longer justified. On the other hand, the full spine radiograph provides more essential information on the spine alignment and balance safer with lower radiation dose than traditional lumbar radiograph since the higher resolution for plain radiograph is no longer needed for detailed diagnostics. This study encourages obtaining full spine radiograph instead of lumbar radiograph for two reasons: to enlarge the diagnostic window and to avoid multiple radiographs from the lumbopelvic region during the treatment of chronic spine diseases. A new development in skeletal imaging, which may eventually replace full spine radiographs, is the standing whole body radiograph with biplanar x-ray imaging system. The weight-bearing alignment of the whole body is revealed and patient positioning for imaging is less liable for error. Compensatory and confounding factors can be calculated and taken into consideration with semiautomatic measurement software and more complex measurement parameters may be utilized more economically and reliably than with time-consuming manual digital measurements from full spine radiographs. This new technique may help introducing the spinopelvic alignment diagnostics and planning into all spine surgeries.

The validation of a deformity-specific PRO instrument provides Finnish physicians and surgeons with a tool to measure HRQoL in relation to degenerative spine diseases independent of the severity of the deformity. The Finnish SRS-30 questionnaire is now available as additional content in the Finnish National Spine Surgery Register. A Swedish language version of the SRS-30 has not yet been produced. The only translated and culturally adapted version of the SRS in Sweden, the SRS-22r, was produced for the Swedish adolescent scoliosis population and it cannot be directly generalized to the Finland-Swedish adult population. Thus, further studies are required to provide the questionnaire in all the official and major languages spoken in Finland.

No previous knowledge existed on the prevalence of degenerative deformities among Finnish patients having chronic spinal diseases with prolonged symptoms. Thus far, the prevalence of spinal deformities in the whole population and among asymptomatic individuals, of whom the majority experience some acute spinal problems during their lifetime, is unknown. A future hope is to be able to study the population-based prevalence of spinal deformities instead of the symptom-related prevalence. To know the prevalence of spinal deformities in the asymptomatic as well as symptomatic population referred for treatment would be important in evaluating the resources needed for physical medicine, rehabilitation and surgical treatment. If mild deformities and compensatory mechanisms such as pelvic retroversion, i.e. enhanced PT, are found in asymptomatic or acute back pain patients, a randomized controlled trial of targeted physiotherapy and exercises could elucidate whether conservative treatment can postpone the onset of chronic back symptoms from degenerative changes and improve patients' health status during their active years.

Once the amount of underlying deformities and compensatory mechanisms in chronic back pain patients is known, the resulting emphasis on comprehensive preoperative evaluation of the spine may also guide spinal surgery into making more individualised choices of surgical techniques and reducing reoperations and avoidable complications. Limiting imaging to short regions and to supine MRI only should be considered clinically inadequate when planning surgery.

With a specialized team and proper patient selection, adults with some co-morbidity can benefit from spinal deformity surgery despite complications and a long recovery time. Further developments issuing from international study teams are providing knowledge on how to avoid the most typical surgery-related complications. The medical complications associated with ASD may be better controlled if a preoperative risk- and frailty evaluation protocol is used in daily practice. Pre- and postoperative ASD evidence-based physical rehabilitation protocols are also scarce and thus present a field for further multidisciplinary research.

Studying the efficacy of the interventions on ASD in a randomized controlled study (RCT) setting is challenging. As pain and disability are the main drivers towards surgical treatment of the ASD rather than the measurable and classified radiographic deformity, the selection of comparable groups is easily biased. The heterogeneity of the components of the ASD leads to individual selection of surgical methods to correct the deformity thus confusing the comparability of intervention groups. Rather than RCT, the observational benchmarking controlled trial (BCT) where the whole clinical pathway may be compared could be more suitable to study the effectiveness of ASD treatment.

This retrospective study enhances the need of a national registry, which includes feasible structured clinical data and PROMs.

7 CONCLUSIONS

Based on Studies I-IV, the following conclusions can be drawn:

I Intra- and inter-rater reliability of measurements of sagittal spinopelvic parameters from digital full spine images with routinely available software tools in an unselected adult population with degenerative spine disorders was high. Parameters that required the identification of several anatomical landmarks were more liable to measurement error, and rater experience had a positive influence on the reliability and repeatability of measurements. Measurement of spinopelvic parameters can be implemented in daily clinical practice in all cases of spinal surgery, providing image quality and rater experience are on an acceptable level.

II This study showed that the novel deformity-specific Finnish version of the SRS-30 was reliable and valid. It has two domains related to deformity that are not covered by other generally used questionnaires. The SRS-30 can be recommended for use among Finnish-speaking patients treated for pain and disability associated with adult degenerative spine and deformities.

III Sagittal imbalance and compensatory mechanisms are common and strongly related to deterioration in physical and social functioning and HRQoL outcomes in symptomatic adult patients with general degenerative spinal disorders and no pre-known ASD. For these patients, the sagittal modifiers of the SRS-Schwab adult spinal deformity classification, categorized into 3 groups, is a useful and a practical tool for detecting various grades of deformity. Analysis of sagittal alignment in the early phases of degenerative spinal disorders can orientate physicians to more individualised physical rehabilitation programs and severe cases can be referred for surgical consultation for diagnosis of the deformity.

IV Long-term radiographic and patient-reported clinical outcomes after ASD surgery remained significantly better than preoperative scores. Risk for complications was high. One third of the patients needed reoperations. Risk for reoperation was highest during the first postoperative year. Meticulous patient selection does not prevent all complications, but good patient satisfaction and outcomes can be achieved regardless of adverse effects. Depression was the only significant predictive factor for poor outcome after ASD surgery, independent of sex or indication for surgery.

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APPENDICES

Appendix 1.

General questionnaire including the Kasari Frequency Intensity Time (FIT-index) questions.

Nimi: ______________________________ Henkilötunnus: ____.____.____ - ________

Sukupuoli: mies ❒ nainen ❒ Paino ______ kg Pituus ______ cm

Puhelin, josta tavoittaa päivisin: ________ - ______________________

1. Perhesuhde: ❒ naimisissa/avoliitossa ❒ leski ❒ eronnut ❒ naimaton

2. Terveydentila: Onko teillä mitään seuraavista sairauksista (ruksatkaa tarvittaessa useampia kohtia):

❒ verenpainetauti ❒ sepelvaltimotauti ❒ eteisvärinä ❒ aivohalvaus
❒ diabetes ❒ keuhkosairaus ❒ kilpirauhassairaus ❒ mielenterveysongelmia
❒ nivelreuma ❒ selkärankareuma ❒ fibromyalgia ❒ polymyalgia rheumatica
❒ osteoporoosi ❒ muu sairaus, mikä ____

3. Tupakointi: ❒ ei ❒ kyllä, keskimäärin _____ savuketta/päivä

4. Alkoholin käyttö: ❒ ei ❒ kyllä, keskimäärin _____ pnä/viikko ja _____ annosta /käyttökerta

(Yksi alkoholiannos vastaa yhtä ravintola-annosta = pullo keskiolutta, 12 cl mietoa viiniä tai 4 cl väkeviä)

5. Koulutus: (merkitkää ylin suorittamanne koulutus):

❒ Kansakoulu/peruskoulu/keskikoulu ❒ lukio ❒ ammattikoulu
❒ opistotutkinto ❒ ammattikorkeakoulu ❒ yliopisto

6. Kuinka monta vuotta yhteensä olette käynyt eri kouluja? ____ v

(Laskekaa aika 1. luokalta siihen saakka kun lopetitte päätoimisen opiskelun).

7. Toimeentulo:

❒ työssä ❒ vuorotteluvapaa ❒ osaeläke
❒ sairauspäiväraha ❒ opiskelija ❒ eläke
❒ kuntoutusraha ❒ työtön ❒ muu, mikä? ________________________
❒ äitiysloma/vanhempainloma ____________________________________

8. Ammatti (myös entinen): ____

9. Mikäli olette työelämässä

a) kuinka pitkään olette ollut selkävaivanne takia sairauslomalla viimeisen vuoden aikana? ___ kk ___ pv

b) kuinka pitkään olette yhteensä ollut selkävaivanne takia sairauslomalla?
___v ___ kk ___ pv

10. Mkäli olette työelämässä, millainen on työnne fyysinen kuormittavuus?
(Rastittakaa yksi vaihtoehto)

☐ **1. Kevyt istumatyö**
Esim. toimistotyö

☐ **2. Raskas istumatyö**
Esim. sarjatyö liukuhihnalla tehtaassa

☐ **3. Ruumiillisesti kevyt seisomatyö tai kevyt liikkuva työ**
Ei toistuvia raskaita kantamisia ja nostamisia. Esim. kauppa-apulainen, nosturinkuljettaja, laboratoriotyö, liikkuva toimistotyö, liikkumista edellyttävä opetustyö.

☐ **4. Ruumiillisesti kevyehkö tai keskiraskas liikkuva työ**
Kumartelemista ja kantamista suhteellisen paljon, kevyitä esineitä (alle 5 kg), paljon portaissa kävelyä tai liikkumista kohtalaisen nopeasti pitkiä matkoja.
Esim. kevyehkö teollisuustyö, metsän mittaus, lähetin työ.

☐ **5. Raskas ruumiillinen työ**
Raskaiden esineiden kantamista, kairaamista, kaivamista, moukarointia tms., mutta välillä myös istumista tai seisomista. Esim. raskaat metalliteollisuuden työt, rakennustyöt, raskaitten työkalujen, tavaroiden tai osien käsittely ja kokoaminen, konein tehtävä maataloustyö.

☐ **6. Erittäin raskas ruumiillinen työ**
Melko jatkuvaa raskaiden työliikkeiden suorittamista. Esim. huonekalujen kantaminen, metsätyö (hakkuu), raskas maataloustyö ilman koneita, kalastus, raskas rakennustyö, kaivamistyö ilman koneita.

Keskimääräinen työaika viikossa ___________ tuntia

11. Liikunta-aktiivisuus (vastatkaa A, B ja C kohtiin)

A. Kuinka usein harrastatte liikuntaa? Huomioikaa myös työmatkat	**Ympyröikää oikeat luvut**
Vähintään 6 kertaa viikossa	5
3-5 kertaa viikossa	4
1-2 kertaa viikossa	3
Muutaman kerran kuukaudessa	2
Kerran kuukaudessa tai vähemmän	1

B. Kuinka rasittavaa harrastamanne liikunta tavallisesti on?	
Erittäin rasittavaa, kovatehoista liikuntaa. Hengästyminen ja hikoilu on runsasta, esim. kilpaurheilu	5
Selvästi rasittavaa liikuntaa, joka aiheuttaa hengästymistä ja hikoilua	4
Kohtalaisen rasittavaa liikuntaa esim. reipas kävely	3
Kevyttä liikuntaa	2
Hyvin kevyttä liikuntaa	1

C. Kuinka kauan liikuntasuorituksenne tavallisesti kestää?	
Pidempään kuin 30 minuuttia	4
20-30 minuuttia	3
10-19 minuuttia	2
Alle 10 minuuttia	1

12. Oletteko harjoittaneet selkäänne viimeisen kuukauden aikana tekemällä,

a) **vartalon lihaksia vahvistavia** harjoitteita
- ❒ en lainkaan
- ❒ satunnaisesti
- ❒ säännöllisesti

_______krt/viikko

b) **selän venytys/liikkuvuusharjoitteita**
- ❒ en lainkaan
- ❒ satunnaisesti
- ❒ säännöllisesti _____ krt/viikko

13. Oletteko käyttäneet **kipulääkkeitä** selkävaivanne vuoksi viimeisen kuukauden aikana?

❒ en lainkaan ❒ kyllä, _____ päivänä kuukaudessa

14. Kuinka kauan nykyinen **selkävaivanne** on jatkunut? _____v _____ kk

15. Kuinka kauan teillä on ollut **selkävaivoja** yhteensä elämänne aikana _____v _____ kk

16. Uskotteko, että terveytenne puolesta pystyisitte **työskentelemään nykyisessä ammatissanne** vuoden kuluttua?

- ❒ Melko varmasti
- ❒ En ole varma
- ❒ Tuskin

17. Oletteko kokenut seuraavaa:

	Ei	Useana päivänä	Suurimpana osana päivistä	Lähes joka päivä
Hermostuneisuus, ahdistuneisuus tai kireyden tunne	☐	☐	☐	☐
Kyvyttömyys hallita tai lopettaa huolehtimista	☐	☐	☐	☐

Appendix 2.

Scoliosis Research Society questionnaire version 30 (SRS-30) Finnish version.

Scoliosis Research Society -kysely, versio 30 (SRS-30)

Muokattu 11/12/03, suomennos 12/2012

Potilaan nimi:____ Ikä: _______

Henkilötunnus: ____________________ - _______ Päivämäärä: __________

Tutkimusajankohta/hoidon vaihe: _____________________ *(tutkija täyttää)*

Lääkäri arvioi selkänne tilannetta huolellisesti ennen hoitoa ja sen jälkeen. Olkaa hyvä ja ympyröikää jokaisesta kysymyksestä yksi parhaiten sopiva vastaus ellei toisin pyydetä. Jos Teidät on jo leikattu, täyttäkää osat 1 ja 2, muutoin vain osa 1.

Kaikki tulokset käsitellään luottamuksellisesti.

Osa 1.

1. Mikä seuraavista kuvaa parhaiten viimeksi kuluneen 6 kuukauden aikana tuntemanne kivun voimakkuutta?
□ Kivuton
□ Lievää kipua
□ Kohtalaista kipua
□ Kohtalaista tai kovaa kipua
□ Kovaa kipua

2. Mikä seuraavista kuvaa parhaiten viimeksi kuluneen kuukauden aikana tuntemanne kivun voimakkuutta?
□ Ei kipua
□ Lievää kipua
□ Kohtalaista kipua
□ Kohtalaista tai kovaa kipua
□ Kovaa kipua

3. Oletteko ollut hyvin hermostunut viimeksi kuluneen 6 kuukauden aikana?
□ En ollenkaan
□ Pienen osan aikaa
□ Jonkin aikaa
□ Lähes koko ajan
□ Koko ajan

4. Jos joutuisitte elämään loppuelämänne nykyisen selkätilanteenne kanssa, miltä se tuntuisi?
□ Oikein hyvältä
□ Melko hyvältä
□ Ei hyvältä eikä pahalta
□ Melko pahalta
□ Erittäin pahalta

5. Miten aktiivinen olette nykyään?
□ Vuoteessa/pyörätuolissa
□ Pääasiassa ei aktiivista toimintaa
□ Kevyttä työtä, kuten kotityötä
□ Kohtalaista ruumiillista työtä ja liikuntaa, kuten kävelyä ja pyöräilyä
□ Täysin toimintakykyinen ilman rajoituksia

6. Miltä näytätte vaatteet päällä?
□ Oikein hyvältä
□ Hyvältä
□ Kohtalaiselta
□ Huonolta
□ Erittäin huonolta

7. Oletteko ollut viimeksi kuluneen 6 kuukauden aikana niin alakuloinen, että mikään ei pysty piristämään teitä?
□ Hyvin usein
□ Usein
□ Joskus
□ Harvoin
□ En koskaan

8. Tunnetteko selässänne lepokipua?
□ Hyvin usein
□ Usein
□ Joskus
□ Harvoin
□ Ei koskaan

9. Millainen on työ-/opiskelukykynne?
□ 100 % (normaali)
□ 75 % normaalista
□ 50 % normaalista
□ 25 % normaalista
□ 0 % normaalista

10. Mikä seuraavista kuvaa parhaiten keskivartalonne ulkonäköä? Määritelmänä on ihmisen keho päätä ja raajoja lukuun ottamatta.
 Erittäin hyvä
 Hyvä
 Kohtalainen
 Huono
 Erittäin huono

11. Mikä seuraavista kuvaa parhaiten lääkkeiden käyttöä selkänne vuoksi?
 Ei mitään
 Perustason kipulääkettä (esim. ibuprofeeni tai parasetamoli) viikoittain tai harvemmin
 Perustason kipulääkettä päivittäin
 Vahvaa kolmiokipulääkettä (esim. oksikodoni, kodeiini, tramadoli) viikoittain tai harvemmin
 Vahvaa kolmiokipulääkettä päivittäin
 Jotain muuta (määrittele tarkemmin)
Lääkitys:

____

____

____

Käyttö: (viikoittain, harvemmin tai päivittäin)

____

12. Rajoittaako selkä kykyänne tehdä kotitöitä?
 Ei koskaan
 Harvoin
 Joskus
 Usein
 Erittäin usein

13. Oletteko tuntenut olonne tyyneksi ja rauhalliseksi viimeksi kuluneen 6 kuukauden aikana?
 En ollenkaan
 Pienen osan aikaa
 Jonkin aikaa
 Lähes koko ajan
 Koko ajan

14. Tuntuuko, että selän kunto rajoittaa henkilökohtaisia suhteitanne?
 Ei lainkaan
 Hieman
 Jonkin verran
 Kohtalaisesti
 Paljon

15. Aiheutuuko teille ja/tai perheellenne taloudellisia vaikeuksia selkänne vuoksi?
 Paljon Kohtalaisesti
 Jonkin verran
 Hieman
 Ei lainkaan

16. Oletteko tuntenut itsenne lannistuneeksi ja alakuloiseksi viimeksi kuluneen 6 kuukauden aikana?
 En koskaan
 Harvoin
 Joskus
 Usein
 Erittäin usein

17. Oletteko viimeksi kuluneen 3 kuukauden aikana ollut sairauslomalla töistä tai poissa koulusta selkäkivun vuoksi, ja jos olette, kuinka monta päivää?
 0
 1
 2
 3
 4 tai useampia

18. Vietättekö sosiaalista elämää enemmän vai vähemmän kuin ystävänne?
 Paljon enemmän
 Enemmän
 Saman verran
 Vähemmän
 Paljon vähemmän

19. Tunnetteko itsenne viehättäväksi, kun selkänne on nykykunnossaan?
 Kyllä, erittäin
 Kyllä, jossain määrin
 En viehättäväksi enkä epämiellyttäväksi
 En kovin paljon
 En lainkaan

20. Oletteko ollut onnellinen viimeksi kuluneen 6 kuukauden aikana?
 En koko aikana
 Pienen osan aikaa
 Jonkin aikaa
 Lähes koko ajan
 Koko ajan

21. Oletteko tyytyväinen selkänne hoitotuloksiin?
 Erittäin tyytyväinen
 Tyytyväinen
 En tyytyväinen enkä tyytymätön
 Tyytymätön
 Erittäin tyytymätön

22. Tulisitteko samaan hoitoon uudestaan, jos olisitte samassa tilanteessa kuin ennen hoitoa?
 Ehdottomasti kyllä
 Todennäköisesti kyllä
 En ole varma
 Todennäköisesti en
 Ehdottomasti en

23. Millaiseksi arvioitte minäkuvanne asteikolla 1–9? (1 on hyvin matala ja 9 hyvin korkea arvo.)
 1 2 3 4 5 6 7 8 9

Osa 2: Vain leikatuille potilaille

24. Miltä nykyinen ulkonäkönne tuntuu verrattuna hoitoa edeltävään ulkonäköön?
 Paljon paremmalta
 Paremmalta
 Samalta
 Huonommalta
 Paljon huonommalta

25. Onko hoito muuttanut selkänne toimintaa tai päivittäisiä toimintojanne?
 Parantanut
 Ei muutosta
 Huonontanut

26. Onko selkänne hoito muuttanut kykyänne nauttia urheilusta tai harrastuksista?
 Parantanut
 Ei muutosta
 Huonontanut

27. Miten hoito on vaikuttanut selkäkipuunne?
 Lisännyt kipua
 Ei muutosta
 Vähentänyt kipua

28. Onko hoito muuttanut itseluottamustanne henkilökohtaisissa suhteissa toisiin ihmisiin?
 Lisännyt
 Ei ole muuttanut
 Heikentänyt

29. Miten hoito on muuttanut muiden ihmisten käsitystä teistä?
 Parantanut paljon
 Parantanut
  Ei ole muuttanut
 Huonontanut
 Huonontanut paljon

30. Miten hoito on muuttanut minäkuvaanne?
 Parantanut
 Ei ole muuttanut
 Huonontanut