Indication and treatment of adult kyphoscoliosis

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A project thesis by Nooman Ahmad and Zein Ahmad by the medical faculty, University of Oslo.

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Abstract

Background: Indication and treatment of adult kyphoscoliosis is a field yet to be fully understood. Symptoms of adult kyphoscoliosis is due to either primary degeneration, arise after elective surgery of the spine or due to trauma. Correction surgery of spinal deformities have a lot of complications and disparity. This type of surgery is increasing in amount, especially at OUS Ullevål.

Aim: This study was done to get an overview of the patients' demographic data, their indication for surgery, the primary operation method, perioperative complications and the radiological outcome.

Material and method: We examined patient journals, operation notes and x-ray images from 74 eligible patients who received spinal corrective surgery at Ullevål from the year 2011-2017.

Results: The mean age of the patients was 62 years old, the majority of them had ASA-class 2 or 3. 21% of the patients had a major complication, 60% of the complications were due to infection. The type of technique with fewest complications was PLF where 49% had at least one revision surgery. The thoracic to lower segment vertebra fixations had a revision rate of 58%. Radiological outcome shows an improvement in SVA and lumbar Cobb's angle.

Conclusion: SP-osteotomies had the highest rate of complications at 25%. 15% of those who underwent PSO had a complication. The TLIF population presented a 40% complication rate**.** As the complexity of the procedure increases, so does the amount of complications and revisions needed. There seems to be a correlation between the length of the fixations and the revision rate. A more standardized method of follow-up is needed to assess the outcome. However, more research should be done on this topic before drawing any conclusions.

List of abbreviations

LL – Lumbar lordosis

SS – Sacral slope

PI – Pelvic incidence

PT – Pelvic tilt

SVA – Sagittal vertical axis

CVD – Cardio-vascular disease

PSO – Pedicle subtraction osteotomy

SP – Smith Peterson osteotomy / Ponte-osteotomy

IPO – Interpedicular osteotomy

TLIF – Transforaminal lumbar interbody fusion

XLIF – Extreme lateral interbody fusion

PLF – Posterior lumbar fusion

Contents

Introduction

The spine

The spine is what keeps our upper body straight. However, it does not have the shape of a straight rod. That is fortunate for us because it gives us the ability to bend our upper body forwards and backwards, to the sides and even rotate it. It has multiple curvatures in the sagittal plane. The stability of the spine is therefore always dependent of the influence (effect) of both ligaments and muscles. However, due to our sedentary lifestyle this natural balance between our muscle groups is fading away.

As one views the spine from a lateral view, it is easy to distinguish between the different types of curvatures. It bends forward in the neck and abdominal part of the spine, this is also known as lordosis. The chest and the pelvic part of the spine bends backwards which is known as kyphosis. This combination of curvatures shapes the spine in a double "S"-shape. An extreme kyphosis in the thoracic part of the spine results in a humpback. The name of a spine that bends to one of the sides is scoliosis(1).

Smith Petersen was the man who presented correction surgery of deformities of the spine in 1945. 73 years later, we still do not have a perfect formula to when, who and how we should operate. Daubs MD et al found some crucial points in their article. The general complication percentage if you are at least 60 years of age and receiving extensive spinal deformity surgery is 37%. They also found out that one out of five patients would suffer from a comprehensive complication. Furthermore, they unraveled that increasing age also mean a much higher chance of suffering from a major complication, 9 times more likely if the age is above 69 years to be precise. However, there were also some positive findings. The patients themselves stated considerable enhancement of their daily function, with a 49% improvement before and after surgery in the Oswestry disability index (2).

Joshua D. Auerbach et al also report a shocking high percentage of complications in their study, encompassing 35% of the people who received 3-column osteotomies. They compared the two common techniques, PSO – pedicle subtraction osteotomy and VCR – vertebral column resection. The comparison gave conflicting results. While PSO had a higher risk (38% vs 22%) of developing a significant complication, ultimately it did not matter as it did not affect the result at two years or more (3).

Life expectancy is increasing in the industrialized world, and a larger part of the population is reaching old age. Spinal deformities have a higher prevalence in the geriatric population, partly explained by degenerative changes, weakness in musculature, and a shift in biomechanics. These deformities cause loss of physical function due to the pain, disability and respiratory difficulties that they inflict on the patient. This, coupled with an increased need to stay active and mobile might give an insight as to why the rate of corrective surgeries is increasing. (4)

In this paper we will try to find out the indications and treatment of adult degenerative spinal deformities, as well as the complications. We have been looking at patients with either scoliosis, kyphosis or a combination of both. We are most interested in the patients who receive surgery due to the combination of both scoliosis and kyphosis, kyphoscoliosis.

Spinal deformities

Scoliosis

In the book *Menneskets funksjonelle anatomi* written by Dahl and Rinvik they define scoliosis as curvatures in the frontal plane. Even though we appear perfectly symmetrical on the outside, that is most certain not the case if you open the human body and peek inside. For instance, we only have one heart which is placed mainly in the left part of the chest. Therefore, it is not a shocking fact that it is quite normal to have a slight scoliosis with convexity towards the right in the chest region, in between a scoliosis with convexity to the left above and beneath the chest scoliosis. However, the explanations to why this occur in otherwise healthy, grown adults are not fully understood, a so-called physiological scoliosis. Dahl and Rinvik state several ideas for why this occurs. One theory is that of a “working scoliosis” due to vast use of the right hand. But this assumption would lead to similar findings in humans that are left-handed, which is yet to be found. Can it have something to do with how the aorta develops in the embryonal stage? They present this as a reason, but that is not essential as a slight scoliosis is not worth stressing over because it does not lead to any problems (5).

However, something that is worth stressing over is a term called static scoliosis. To explain why and how this occur imagine building a bridge between two towers. If you want the bridge to be stable then it should form a 90-degree angle on both the towers, making it straight. The pelvis can be viewed as the bridge and our lower limbs as the towers. Now if the bridge itself is crooked, balancing an object on that bridge would be difficult, it would have to adapt to the unstable angle the bridge has. This is what happens with our spine when there is a difference in length in the lower limbs through a wrong placement of the pelvis, an abnormal angulation. This may result in the development of a compensatory scoliosis to regain the balance of the upper body, also known as a static scoliosis(5). Furthermore, Dahl and Rinvik also explains that another reason for pathological placements of the pelvis is due to diseases in one of the hip joints(5).

The reason for a scoliosis can also be traced to the spine itself. The vertebras may have structural damage or deformities, for example a vertebra with a wedge-shaped body or structural changes due to osteoporosis. This kind of pathology is named a structural scoliosis(5). If the Cobb's angle is at least or greater than 25 degrees on a side bending x-ray, then it fulfills the criteria of being a structural scoliosis(6)

Another type of scoliosis mentioned by Dahl and Rinvik is named avert scoliosis. This is something one can see clinically in patients with a prolapse with affection of the nerve. They will subconsciously bend their back to one of the sides to lessen the pressure exerted on the nerve. They will of course bend their back to the opposite of where the disc is protruding, making more space for the nerve root and reducing the pressure in the wounded area(5).

A bad posture over time will result in a fixation of the vertebral column in a bend shape. The law of gravity does also apply to the human body. When the trunk increases in size it will also exert more pressure on the spine. This will not surprisingly result in a slight bend, which is not dangerous. However, if the angle of the bend keeps rising it may lead to problems. There is not infinite of space inside the chest and abdominal cavity. When the spine keeps bending it will result of lowering of the breast bone (sternum) due to the ribs being forced against each other. This brings us back to the cavities of the chest and abdomen, which will naturally decrease in size and as a result the respiration movements get impaired(5).

To understand the development of the pathological curvatures in the spine one needs to keep in mind that the vertebral column is only set in the median plane as long as the pelvis occupies a completely symmetrical position of height. This is due to how the spine and the pelvis is connected. The book exemplifies this is a magnificent manor, when we are standing on one foot that is elevated, the pelvis on the opposite side will lower itself. This will lead to the spine curving to restore balance and minimize the muscle effort needed to keep a standing posture. The upper body's line of gravity will try to fall as close to the center of the line connecting the two hip joints(5).

The lumbar column will bend with the convexity to the side where the pelvis is lowest. This curvature will result in a compensatory curvature of the thoracic column to the opposite side. This is of course temporary and will normalize when the pelvis is straightened. Only when the cause itself becomes permanent, as when one leg is shorter than the other, will the curvature of the spine be fixated(5).

Kyphosis

We are now going to shed light over the term kyphosis. Kyphosis is described by Olav Reikerås and Jan Erik Madsen as a normal or increased curvature of the vertebral column when it is viewed from the side, especially in the thoracic part of the spine. As mentioned earlier the spine has the shape of a double S. This is not pathological, it is normal to have slight curvatures both bending forwards and backwards. However, as with everything else in life, when certain thresholds are surpassed the normal curvatures of the spine becomes pathological. Reikerås and Madsen state several reasons a human can develop kyphosis. It can be congenital (very rare), different type of diseases (ankylosing spondylitis or rickets), damage to the vertebras (fractures) or the mere process of growing old. An example they give is that it is not unusual for some older people to walk with their spine bent forwards. Their vertebras are not what they used to be and as a result they fall a little deeper in the front of the body. Usually one would counter this by bending backwards above and beyond the thoracic column, however, due to natural occurring stiffness the spine can no longer compensate and it is portrayed by their walk(7).

The term hyperkyphosis is explained by "Progressive spinal kyphosis in the aging population" as excessive curvature of the thoracic spine. The reasons for development of this state is not easy to point out, as there are multiple factors involved in this condition. The two central components that give rise to the sagittal curvature are the vertebral bodies and the discs in between them. This means that if there exist any form pathology that will result in anterior wedging of the vertebras or a disproportionate breakdown (collapse) of the disc, it will lead to hyperkyphosis. The authors also found out that vertebral fractures increase the risk of developing thoracic kyphosis. Furthermore, they also found out that there is a solid link between osteoporosis, vertebral fractures and hyperkyphosis. Now if we were to look for reasons of this condition specific in the thoracic part of the vertebral column, then we would find that there is a diversity of idiopathic, genetic and metabolic conditions that give rise to hyperkyphosis. However, there is a disease, namely Scheuermann disease which with its approximated prevalence of 0.083 that is the most mutual cause of hyperkyphosis. This disease also have a genetic component(4).

This condition has many negative health effects and few viable treatments. It negatively affects physical and pulmonary function and increase the risk for vertebral fractures and falls. Furthermore, this condition is also connected with pain in the back and disability and decreased quality of life. The evidence for conservative treatment indicates that it may help in decreasing and postponing hyperkyphosis. The condition alone does not warrant surgical correction, however, it has to be strongly accounted for when people with multiple spinal deformities undergo surgery(4).

Pelvic and spinal parameters

Sagittal balance plays a role in the identification of spinal deformities. This balance is determined by the different biomechanical forces that affect the pelvic, and in turn the spine. Using landmarks of the pelvis in sagittal view, an angle has been constructed that allows us to analyze the anatomical characteristics of the pelvis in a consistent way(8).

This angle is known as the pelvic incidence, and its construction will be explained later in method. The pelvic incidence is set and unique for every individual. There are no good or bad pelvic incidences, the measure is merely a tool to retain consistency when examining the pelvic parameters. The angle of the pelvic incidence is also the sum of two other parameters known as the pelvic tilt and the sacral slope(8).

The pelvic tilt angle is a measure for the inclination of the pelvis in sagittal view. Normally it has a small forward tilt. A higher pelvic tilt angle leads to a more horizontal sacral plateau(8).

Sacral slope is a measure for the sacral plateau angle in relation to a horizontal line. This plateau is the base of the spine, and the sacral slope will as a consequence decide the position of the lumbar spine(8).

The sacral slope angle is correlated with a spinal parameter known as the lumbar lordosis. The lumbar lordosis is the degree of lordosis present in the lumbar spine(8).

Another important spinal parameter in assessing spinal sagittal balance and deformity is the sagittal vertical angle. The SVA shows how far out of balance the spine is, using anatomical landmarks in full length sagittal view (9, 10).

The Cobb's angle is a way of finding out the extent of the spinal curvature and is also a way to evaluate whether the patient has scoliosis. This is done by examining the angle between the most tilted top and bottom vertebrae in coronal plane(11).

Treatment

Conservative

The goal of conservative treatment of spinal deformities is to observe if there is further progression and stop further progression of the condition. It is essential to remember that degenerative changes in the spine is a natural part of the aging process. As long as the pathological changes do not hinder living a normal life or give any other symptoms there is no reason to label patients with diagnoses. Furthermore, it is the degree of the deformity, its further progression or if it has symptoms that determine if it is indication for treatment.

Conservative treatment of scoliosis is dependent on the patient's age and the degree of scoliosis in Cobb's angle. Children are offered corset-treatment if their Cobb's angle is larger than 30 degrees. The corset is worn all but one hour of the day and the aim of this treatment is to stop the progression, as the corset cannot reduce the scoliosis. The children are monitored with x-ray-controls every half year until they are fully grown. If the angle is larger than 40 degrees in children and 50 degrees in adults, operation is offered (12). At Rikshospitalet in Oslo they set the cutoff on Cobb's angle at 25 degrees for corset-treatment. Also, Haukeland University Hospital in Bergen use night corsets on the children that are older than 10 years of age and compliant, if not it is as explained above.

Conservative treatment of kyphosis is similar to that of scoliosis. If the angle is below 50 degrees, then the treatment is conservative with physical therapy and x-ray-controls every half year. An angle between 50 and 80 degrees is indication for corset-treatment, also 23 hours in the day. When the kyphosis is fixated and the angle surpasses 80 degrees operative treatment is recommended according to Dippmann et al (12). However, we have found out that kyphosis larger than 30 degrees may be an indication for operation, at least at OUS Ullevål. Nonetheless the factor that is most important is the sagittal vertical axis, if the axis is in balance. A positive balance above 5cm may gradually lead to operation.

Surgical treatment

In order to understand the surgical methods, we believe it is crucial to understand how the pathological processes affect the spine. It comes down to balance. A normal, healthy spine is in balance with itself and the rest of the body. It does not hinder natural movement of the body nor does it cause pain due to narrowing the space inside or increasing pressure on structures in the spine. When spinal deformities are allowed to grow, they destroy the natural occurring balance in the spine. They misalign the angles resulting in pathological ways of carrying the weight. As a result, the line of gravity is improperly distributed. This will over time lead to loss of function, pain and loss of life quality.

The goal of corrective surgery is to normalize the pathological processes. It is easy enough to understand that this means we need to open up the spine in order to get access to the pathology. There are several ways of reaching the pathology. We can go in from the back, from the sides or from the front depending on where in the vertebral column the pathology lies. When we are inside, we have the opportunity to rearrange or reshape the spine. This is done by cutting in the vertebras or fusing them together, fixating with screws etc. However, by doing so we may do more harm than good if we inflict more pain or loss of function. This is a risk patients are aware of as this kind of surgery usually is reserved as a last resort.

In the article "Pedicle subtraction Osteotomy for the treatment of fixed sagittal imbalance" Bridwell et al explain how to restore sagittal balance and which two approaches are the most used, namely Smith-Peterson osteotomy and pedicle subtraction osteotomy. The similarity between SP-osteotomy and PSO is the shortening of the posterior column. However, the difference is the magnitude of correction, 5-10 degrees a segment with Smith-Peterson osteotomy versus 25-30 degrees per Pedicle subtraction osteotomy. This is due to the difference in operation techniques. (13)

Smith-Peterson osteotomy (SPO) is a wedge osteotomy with an opening. The posterior part of the disc space is used as an axis of movement. Parts of the posterior structures are then removed, including bilateral facet joints, some of the lamina and posterior ligaments at the osteotomy site. In other words, the posterior column is shortened while the anterior column is lengthened (14). This technique can be used for corrections both in the sagittal and coronal plane(15). Interpedicular osteotomy (IPO) is a form of SPO where a cage is inserted intervertebrally to add correction.

Pedicle subtraction osteotomy (PSO) is an osteotomy over three columns. It leaves a closed wedge. Posterior parts are also resected, as well as a V-shaped wedge from the bone. The size of this wedge is in correlation with the extent of correction needed. The posterior column is shortened, but the anterior column is not lengthened. Rod-screw constructs are used for stabilization. This is a more complex and demanding osteotomy procedure (14, 16).

This of course, leads to the following conclusion; you would need to several SP-osteotomies, about 3-4 to get the angulation similar to that of one PSO. Also, with PSO there is no need to touch the anterior column (13).

Other correctional procedures are transforaminal lumbar interbody fusion (TLIF) and posterior lumbar fusion (PLF). When performing a TLIF, a facetectomy is done, and a bone graft or cage can be is inserted in the intervertebral space, additional fixation of the level is added (17). In PLF, an incision in the lower back is used to gain access to the spine. From this opening, decompression and fixation with screws is possible for immediate stability until the fusion is complete.

In the article «Effect of the indirect neural decompression through Oblique lateral interbody fusion for degenerative lumbar disease» Fujibayashi S et al tell that a new type of LLIF – lateral lumbar interbody fusion, the OLIF – Oblique lateral interbody fusion had great results in the treatment of spinal stenosis. OLIF, LLIF, XLIF are procedures which form a lateral incision going retroperitoneal. It is possible to insert a hyperlordotic cage and then create a great correction of the lumbar spine. If stable, the cage can be left alone, if not, dorsal fixation is needed in addition. It was successfully decompressed with this new technique without any neural complication. It is an indirect decompression, the entrance to the lumbar spine is retroperitoneal through the anterior oblique. This procedure means that the Psoas muscle is left intact (18). The amount of complications and disparity after the surgical treatment is something that tells us that this is a field that needs more research.

Aim of study

The aim of this study is to increase the knowledge of advanced corrective spinal surgery. In a retrospective study we study the indications to see what kind of patients that are eligible for surgery, what kind of surgery they receive, what kind of complications arise and how it goes after the surgery.

Material and method

We went through surgical notes and patient journals from year 2011 to the end of 2017 at the orthopedic ward at OUS Ullevål. We selected patients who were at least of 25 years of age with spinal fixation for the correction of spinal deformity. Some of these patients were operated due to trauma; these were ruled out as they were not relevant to our task. Of 85 patients that had surgery, were 74 met the inclusion criteria. We then extracted information from their journals and operation logs regarding their sex, age, if they smoked cigarettes, if they had diabetes, their body mass index, what kind of co-morbidities they had, what their ASA-score was, if they had prior surgery in the back before. We also looked at the surgical procedures. Naturally, we also noted the type of surgical procedure that was performed on the patient. Their post-operational outcomes, as well as radiological information was also registered.

Retrospective data collection

Patients

We selected patients that had underwent an osteotomy or fixation of at least 3 spinal levels (See table 1). The patients had to be more than 25 years of age. All patients were operated at Oslo university hospital, Ullevål, spinal section.

Joshua D. Auerbach, Lawrence G. Lenke et al define major and minor complications in their article (3). We looked after major complications both perioperative and post-operative. Were there any deaths due to surgery or wrong level surgery? This also included nerve root injury or damage to the spinal cord leading to neurological symptoms or deficits. Cardiovascular complications such as myocardial infarct, cerebrovascular accidents, deep venous thrombosis etc. Deep wound infections required revision surgery. These were naturally complications that led to an extended hospital stay which was also documented in patient journals.

Surgical reports

We went through all available surgical reports of all selected patients. Surgical reports would not always be precise enough in describing the different methods used in the operations. A total of four surgeons performed all the operations, working in pairs on each operation.

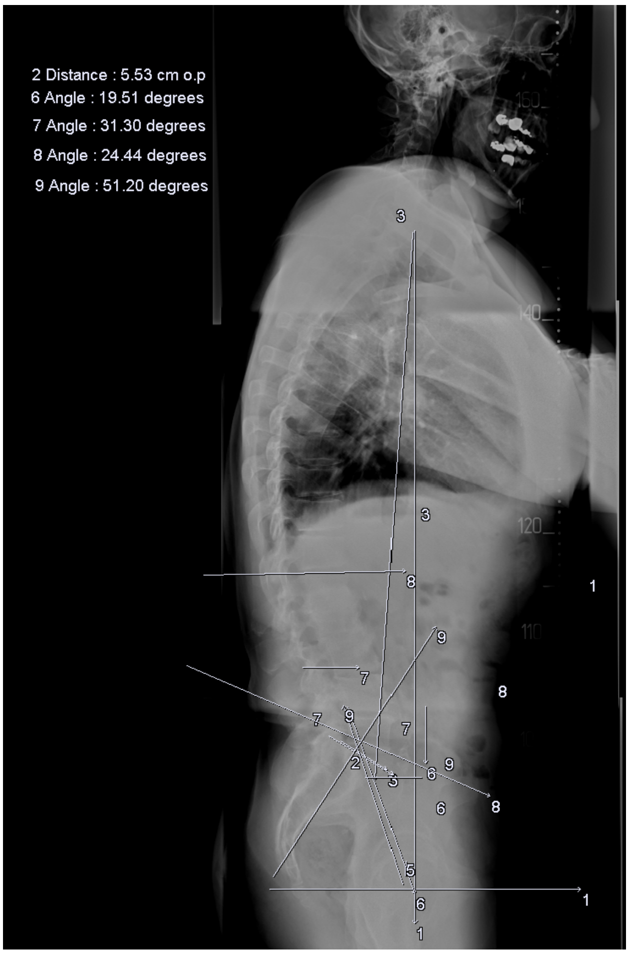
Table 1: Dorsal fixated levels and osteotomied levels

Dorsal fixated levels	**Frequency**	**Percent%**		**Osteotomied levels**	**Frequency**	**Percent%**
None fixated	2	2,7		No Osteotomy	18	24,3
Missing	2	2,7		Missing	3	4,1
Th4-Th11	1	1,4		Th8	1	1,4
Th6-Th10	1	1,4		Th8-Th10	1	1,4
Th8-L2	1	1,4		Th11	1	1,4
Th9-L3	1	1,4		Th12	3	4,1
Th10-L2	1	1,4		Th12-L1	1	1,4
Th10-L4	2	2,7		Th12-L2	1	1,4
Th10-L5	3	4,1		Th12-L3	2	2,7
Th10-S1	5	6,8		Th12-S1	1	1,4
Th11-L1	1	1,4				
Th11-L4	1	1,4		L1	5	6,8

Th11-L5	2	2,7	L1-L2	1	1,4
Th11-S1	7	9,5	L1-L2, L3-L4	1	1,4
Th12-L2	2	2,7	L1-L2, L4-L5	1	1,4
Th12-L5	6	8,1	L1-L4	1	1,4
Th12-S1	4	5,4	L1-L5	1	1,4
			L2	2	2,7
L1-L5	6	8,1	L2-L3	3	4,1
L1-S1	3	4,1	L2-L4	5	6,8
L2-L5	5	6,8	L2-L5	1	1,4
L2-S1	12	16,2	L3	6	8,1
L3-L5	1	1,4	L3-L4	8	10,8
L3-S1	4	5,4	L3-L5	1	1,4
L4-S1	1	1,4	L4	1	1,4
			L4-L5	4	5,4
			L4-S1	1	1,4
Total	74	100		74	100

Conventional radiology

We also went through their x-rays prior and after the operation. We focused on spinal and pelvic parameters from standing patients as long as we had appropriate radiographs available. We measured PI – pelvic incidence, PT – Pelvic tilt, SS – sacral slope, LL – lumbar lordosis, SVA – sagittal vertical axis and Cobb’s angle in the lumbar part of the spine.



Nearly all of the radiographs taken prior to the operation were included in a standardized scoliosis protocol. A scoliosis protocol consists of radiographs of the whole spinal column where PI, PT, SS, SVA and Cobb’s angle were described by a radiologist. Only lumbar lordosis was not included in the measurements. When measurements were missing, we emphasized performed a standardized measurement of the missing parameter.

The definitions and methods explained by Geiger et.al were used to decide how we would measure the angles in a standardized way(19). These methods were utilized when measuring angles that were not described by a radiologist.

Image 1: Scoliosis protocol x-ray in sagittal view showing SVA(2), pelvic tilt(6), sacral slope(8), and pelvic incidence(9) in a patient with kyphoscoliosis

The **pelvic incidence** was measured by the angle created when a perpendicular line on the middle of the tangent of the sacral plateau was adjoined by a line from the center of the femoral heads. Pelvic tilt was measured with one ray being a line from the center of the femoral head to the center of the sacral plateau, and the other ray being the vertical. **Sacral slope** was determined by the angle between a tangent of the superior endplate of S1 and a horizontal line. **Lumbar lordosis** was measured by the angle between the lines from the cranial endplate of L1 and the caudal endplate of L5(19). The distance between a straight line from the center of the body of C7 and the postero-superior corner of S1 was used to measured sagittal vertical axis; SVA(9, 10). These measurements were done in sagittal view.

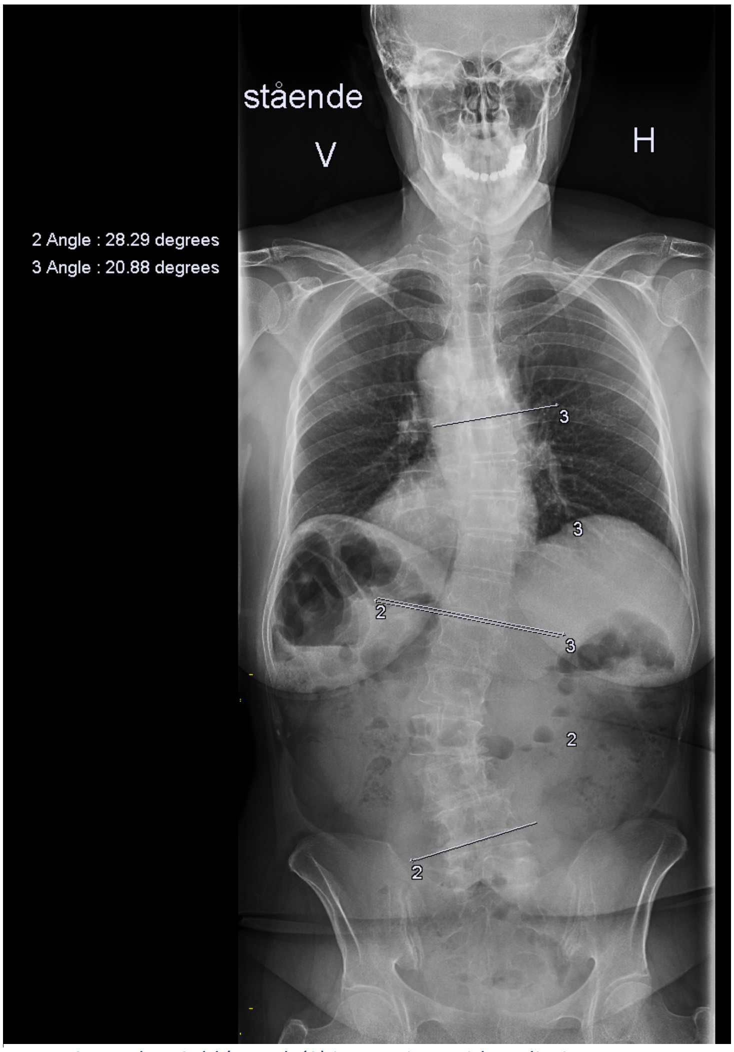


Image 2: Lumbar Cobb's angle(2) in a patient with scoliosis

Lumbar Cobb's angle was measured with the angle between tangents of the superior endplates of the most tilted top and bottom vertebrae in the lumbar spine. This was done in a coronal view(11).

Sometimes it was also a scoliosis protocol at the 6 months to 1-year control. Otherwise, the x-rays taken after the operation would differ from x-ray of the different parts of the spine. Mostly it was an x-ray of the vertebral column stretching from the lumbar part to the sacrum. Sometimes it would only be of the thoracic part, or all the way from the thoracic part to the sacrum. The quality of the x-rays after the operation was not always good enough to be able to measure the angles right. Summarized the x-rays after the operation had massive variation in types of images and their coverage, this naturally led to variations in what parameters we were able to measure.

Statistics

The data collected was first registered in a spreadsheet in Microsoft Excel 2016, where all the parameters were used as a template in filling out data. The data for parameters were categorized by the use of a registry, while others were simply numerical or binary values. Descriptive information was also registered in the few cases where this was beneficial. The parameters and their registries were then defined in IBM SPSS Statistics 25. The data was copied from the Excel spreadsheet into SPSS. The data was analyzed with descriptive statistical tools.

Ethics

This project thesis is part of a larger study by Center for Implant and Radiostereometric Research Oslo (CIRRO). The protocol for this study has been approved by the regional ethics committee (2017/1378/REK nord). All the data were treated anonymously.

Results

Patient demographics

Median age at operation time was 63 years old. The youngest person who was operated and included in the study was 28 years old, while the oldest patient was 81 years old. 51% of the patients were female, while 49% were male. The ASA physical status classification shows that the majority of the people were in ASA class 2, however almost 1/3 out of the patients were in ASA class 3 which means they had a severe systemic disease. About 1/5 of the patients were obese. 24% of the patients had neither kyphosis nor scoliosis, this is nearly ¼ of the patients. While 27% of the patients had both of these diseases. 28% of the group had only kyphosis, 18% of the group had only scoliosis (table 2).

Table 2: Patient demographics

Age when operated – Mean (SD)		62 (11)
Gender of patient (n)	F	38
	M	36
Patient's ASA (n)	1	5
	2	44

	3			24
Obesity (n)	No			60
	Yes			14
Does the patient have scoliosis (n)	Unknown	Does the patient have kyphosis	Unknown	1
			Yes	1
			No	0
	Yes	Does the patient have kyphosis	Unknown	0
			Yes	20
			No	13
	No	Does the patient have kyphosis	Unknown	0
			Yes	21
			No	18

Complications

21% of the people who underwent primary surgery had a major complication. Approximately 56% of the people who were obese had complication during their primary surgery and all of them had infection as their complication. Compared to the non-obese population, the complication rate was on 18%. However, for both obese and non-obese people the dominating complication was infection, but the non-obese group had a more diverse distribution of complications (table 3).

There were 6 people who had Diabetes when operated. 2/3 out of this population had a complication, and infection was the only type of complication in this group. Compared to the non-diabetic group, the complication risk was 17%. Again, the dominating complication is infection. When it comes to the people with cardio-vascular disease, which was by far the biggest comorbidity with 44% of the patients having it, none of them had any cardiovascular complication. 57% of the people had complications, compared to the non CVD-group where only 9% had any complication. As mentioned above, the complication that was most prominent was infection, amounting for 2/3 of the complications for the CVD-group.

Table 3: Comorbidity and complications, what complications occurred, if any?

Comorbidity		No complication (n)	Nerve injury (n)	Cardiovascular complications (n)	Infection (n)	Other (n)
Obesity	No	47	3	1	4	2
	Yes	9	0	0	5	0
Diabetes	No	54	3	1	5	2

	Yes	2	0	0	4	0
CVD	No	35	1	1	1	0
	Yes	21	2	0	8	2

Primary surgery

Out of the 71 operations we have data on, the type of operations with n > 10 are SP-osteotomy, PSO, TLIF and PLF (table 4).

When it comes to SP-osteotomy, almost 1 out of every 4 person who receives this surgery would develop some kind of complication. In comparison only 15% of the PSO-operations would have a complication. TLIF also had a fair share of complications, 40% in fact. The operation with fewest complications was the PLF, with only 7% of the people developing a complication. SP combined with IPO had a 100% success rate, as well did IPO alone. PSO and SP had a 100% failure rate. Corpectomy had a 33% complication rate as well.

We did not detect any wrong level surgery, respiratory complications or anaphylactic shock as a major complication in any of the operated patients.

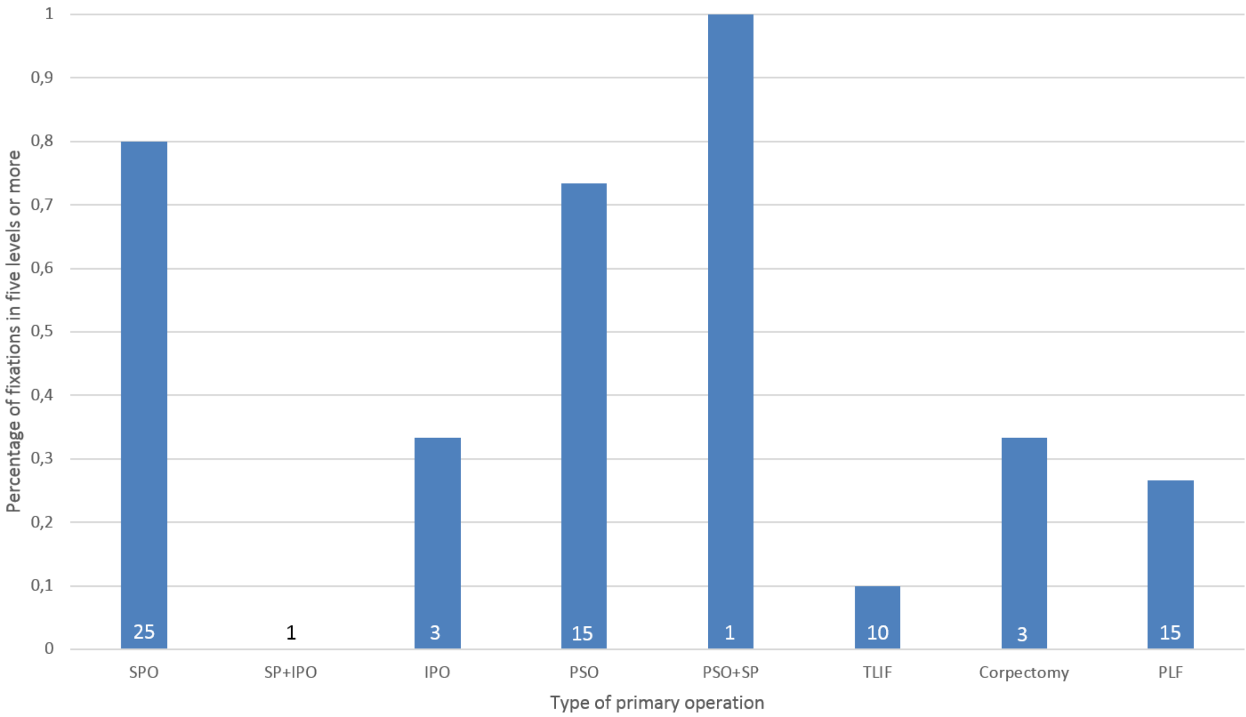
Table 4: Type of primary operation and complications

		Type of primary operation								Total
		SP-Osteotomy	SP and IPO	IPO	PSO	PSO and SP	TLIF	Corpectomy	PLF	
What complications occurred, if any?	No complication	19	1	3	11	0	6	2	14	56
	Nerve injury	2	0	0	0	0	0	1	0	3
	Cardiovascular complications	0	0	0	0	0	1	0	0	1
	Infection	3	0	0	1	1	3	0	1	9
	Other	1	0	0	1	0	0	0	0	2
Total		25	1	3	13	1	10	3	15	71

80% of the SP-osteotomies were fixations of 5 levels or more, where 36% were from the thoracic part of the spine to the sacral part. 73% of the PSO were also fixated 5 levels or more (table 5). 10% of the TLIFs were fixated 5 levels or more and 27% of the PLF's were fixated for 5 levels or more.

Table 5: Type of primary operation and length of fixations.

		No osteotomy	SP - Ponte-/smith petersen osteotomy	SP and IPO	IPO - interpedicular osteotomy	PSO - pedicle subtraction ostetomy	PSO and SP	TLIF	Corpectomy	PLF	Total
Dorsal fixated levels	Missing	0	1	0	0	0	0	1	0	0	2
	None	1	0	1	0	0	0	0	0	0	2
	Th4-Th11	0	1	0	0	0	0	0	0	0	1
	Th6-Th10	0	1	0	0	0	0	0	0	0	1
	Th8-L2	0	0	0	0	1	0	0	0	0	1
	Th9-L3	0	0	0	0	1	0	0	0	0	1
	Th10-L2	0	0	0	0	1	0	0	0	0	1
	Th10-L4	0	0	0	0	1	0	0	1	0	2
	Th10-L5	0	1	0	0	2	0	0	0	0	3
	Th10-S1	0	4	0	0	0	1	0	0	0	5
	Th11-L1	0	0	0	0	1	0	0	0	0	1
	Th11-L4	0	0	0	0	1	0	0	0	0	1
	Th11-L5	0	1	0	0	0	0	0	0	1	2
	Th11-S1	0	3	0	0	4	0	0	0	0	7
	Th12-L2	0	1	0	0	0	0	0	1	0	2
	Th12-L5	0	4	0	1	1	0	0	0	0	6
	Th12-S1	0	2	0	0	0	0	1	0	1	4
	L1-L5	0	3	0	1	1	0	1	0	0	6
	L1-S1	0	0	0	1	0	0	0	0	2	3
	L2-L5	0	1	0	0	0	0	1	0	3	5
	L2-S1	0	2	0	0	1	0	2	1	6	12
	L3-L5	0	0	0	0	0	0	1	0	0	1
	L3-S1	0	0	0	0	0	0	3	0	1	4
	L4-S1	0	0	0	0	0	0	0	0	1	1
Total		1	25	1	3	15	1	10	3	15	74



Graph 1: Percentage of operations with fixations in five levels or more. Sample size (n) inside the columns.

Revisions

Gender

55% of the males and 45% of the females were revised, where 52% of the male group needed at least 1 or more revisions. In nearly 80% of the cases one revision was sufficient. 45% of the female group needed at least 1 or more revisions. Only 41% of the cases managed with one revision. The highest amount of revisions in the male group was 3, with only one male patient needing it. There were 4 female patients with at least 4 or more revisions, with one female needing revision 7 times (table 6).

Table 6: Number of revision with gender differentiation

		Gender of patient		Total
		F	M	
Number of revisions	0	21	17	38
	1	7	15	22
	2	6	3	9
	3	0	1	1
	4	2	0	2
	5	1	0	1
	7	1	0	1
Total		38	36	74

Type of operation

When only SP was used as primary correctional procedure, 44% were successful in form of not needing any revisions. Out of the people who needed revisions, 43% managed with one revision, whereas 57% needed at least two or more. Of all patients operated with PSO 50% were revised. Out of the people who needed revision, 88% only need it once, however, one person underwent revision surgery 7 times (table 7). TLIF had a 70% chance of revision, but not more than twice. 80% of the PLF-surgeries did not need any other revision.

Table 7: Number of revisions

		Type of primary operation									
		No osteotomy	SP - osteotomy	SP and IPO	IPO	PSO	PSO and SP	TLIF	Corpectomy	PLF	Total
Number of revisions	0	1	11	0	2	7	0	3	2	12	38
	1	0	6	0	0	7	1	5	1	2	22
	2	0	5	0	1	0	0	2	0	1	9
	3	0	0	1	0	0	0	0	0	0	1
	4	0	2	0	0	0	0	0	0	0	2
	5	0	1	0	0	0	0	0	0	0	1
	7	0	0	0	0	1	0	0	0	0	1
Total		1	25	1	3	15	1	10	3	15	74

Wound infection (16%), screw loosening (20%) and paralysis / pain (26%) are the common causes of revisions (table 8).

Table 8: Indication of revisions

		Type of primary operation									Total
		No osteotomy	SP-osteotomy	SP and IPO	IPO	PSO	PSO and SP	TLIF	Corpectomy	PLF	
Reason for revision surgery	No revision	1	11	0	2	7	0	3	2	12	38
	Wound infection	0	2	0	0	0	1	2	0	1	6
	Wound infection, screw loosening	0	0	0	0	1	0	1	0	0	2
	Wound infection, screw loosening, stenosis and paralysis/pain	0	1	0	0	0	0	0	0	0	1
	Wound infection, screw loosening and paralysis/pain	0	0	1	0	0	0	0	0	0	1
	Wound infection and stenosis	0	1	0	0	0	0	0	0	0	1
	Wound infection and paralysis/pain	0	0	0	1	0	0	0	0	0	1
	Screw loosening, stenosis and paralysis/pain	0	1	0	0	0	0	0	0	0	1
	Screw loosening and paralysis/pain	0	6	0	0	1	0	2	0	1	10
	Hardware failure and paralysis/pain	0	0	0	0	1	0	0	0	0	1
	Stenosis and paralysis/pain	0	1	0	0	1	0	0	0	0	2
	Paralysis/pain	0	2	0	0	1	0	1	1	1	6
	Pseudoarthrosis	0	0	0	0	1	0	0	0	0	1
	Correction of implant	0	0	0	0	1	0	0	0	0	1
	Injury to organs	0	0	0	0	1	0	1	0	0	2
Total		1	25	1	3	15	1	10	3	15	74

Revisions by fixated levels

Most fixations started in L2 (24.3%), and most fixations ended in S1 (50%). L3 was involved in 21/53 (29%) osteotomies.

Thoracic to lower segment vertebrae fixations had a revision rate of 58%. If we narrow these fixations down to fixations that involve 5 levels or more, the revision rate increases to 66%.

If we are to separate the fixations from the thoracic part of the spine to either lumbar or to sacral, the respective amount of fixations are 56% and 44%. One can observe a notable difference between the revision rates in the thoracolumbar and thoracosacral spine, with the first having a revision rate at 40%, while the latter has a revision rate at 81%. All of these fixations were over five levels. Lumbar to lower vertebra had a revision rate of 34% (table 9).

Table 9: Dorsal fixated levels and number of revisions

		Number of revisions							
		0	1	2	3	4	5	7	Total
Dorsal fixated levels	Missing	0	2	0	0	0	0	0	2
	None	1	0	0	1	0	0	0	2
	Th4-Th11	1	0	0	0	0	0	0	1
	Th6-Th10	1	0	0	0	0	0	0	1
	Th8-L2	1	0	0	0	0	0	0	1
	Th9-L3	0	1	0	0	0	0	0	1
	Th10-L2	1	0	0	0	0	0	0	1
	Th10-L4	2	0	0	0	0	0	0	2
	Th10-L5	2	0	0	0	0	1	0	3
	Th10-S1	2	1	1	0	1	0	0	5
	Th11-L1	1	0	0	0	0	0	0	1
	Th11-L4	0	1	0	0	0	0	0	1
	Th11-L5	1	0	0	0	1	0	0	2
	Th11-S1	0	5	1	0	0	0	1	7
	Th12-L2	2	0	0	0	0	0	0	2
	Th12-L5	2	3	1	0	0	0	0	6
	Th12-S1	1	2	1	0	0	0	0	4
	L1-L5	3	2	1	0	0	0	0	6
	L1-S1	2	0	1	0	0	0	0	3
	L2-L5	4	1	0	0	0	0	0	5
	L2-S1	8	2	2	0	0	0	0	12
	L3-L5	1	0	0	0	0	0	0	1
	L3-S1	1	2	1	0	0	0	0	4
	L4-S1	1	0	0	0	0	0	0	1
Total		38	22	9	1	2	1	1	74

Conventional radiography

Pre-operative and control imaging

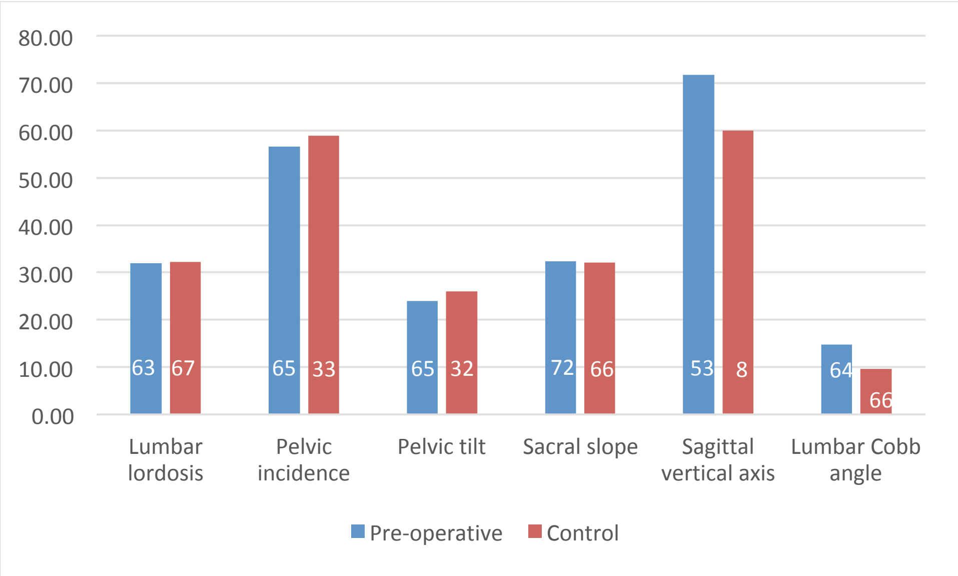
The longest period before the operation at which a standing X-ray was taken was 43 months. The shortest was within less than half a month. The mean was 6.6 months before operation, while the median for standing x-ray images was 6 months.

Longest period after operation at which a standing x-ray control was taken is 15 months. The shortest is 3 months after. Mean shows 9.5 months, while median shows 10 months.

Pelvic parameters

The results shows a reduction in SVA, reducing the kyphosis. However, n was only 8 in the control croup when it comes to SVA.

Graph 2: Pelvic parameters before and after operation



Discussion

Summary

The aim of the study was to collect data regarding demographics, complications, revisions and radiology for patients receiving extensive spinal surgery such as osteotomies with fixation of more than 3 levels. It is known that this surgery is complex and accompanied with a high risk for complications, failures and reoperations. This patient population is in their sixties, often has additional systemic diseases and many of them had complications during or after their surgery.

Patient demographics

The majority of the patients received surgery in their early sixties, hence dealing with a somewhat older population. Naturally, this leads to the following question: Is this usually the age for people undergoing spinal surgery of this type? Several studies of spinal surgery have a mean age around 50-60(2, 3, 20, 21). This is understandable as spinal deformities need time to develop and this kind of complex surgery is usually the last step in the treatment. Instead of delaying this type of operation, one should maybe start to think about the possibility to operate before it is a last resort. If we were to approach the problem before it gets out of hand, there might be a better chance of a successful outcome.

The majority of these patients were in ASA class 2, yet there were a high amount of patients with ASA class 3. This shows that the patients in this population had other systemic diseases as well. The type of surgery these patients were receiving is complex. It does not make it easier that they are multimorbid as well. This may interfere with the results of the surgery. One of the reasons that patients who suffer from spinal deformities have a higher ASA-class might be that their condition is hindering them being physical active and affects their lifestyle.

Somani S et al compared ASA-class and postoperative outcomes subsequent to adult spinal deformity surgery in 5805 patients. As one would think, if you have more than one problem when you undergo extensive surgery, the risk of mortality will be increased, with OR being 21.0 (22). We did not have any patients with ASA group 4 or higher and none of the patients died due to surgery. The ASA distribution shows that these patients have reduced physiological status. The mean age of operations in this study was 62 years. Increased age is correlated with a higher cardiovascular risk(23).

Kyphosis was registered at a higher percentage than scoliosis. This does not necessarily mean that kyphosis is more common than scoliosis in general. That is because OUS Ullevål Hospital has a nationwide function to take care of kyphotic patients. Nearly all of the patients in Norway are operated at Oslo university hospital, Ullevål.

Complications during primary surgery

SP-osteotomy

We had four primary surgery types were n was at least 10 or more. Out of those operations, SP-osteotomies had a high risk of complications, almost 25%. Is this something that is to be expected? No certainly, SP-osteotomy is a relatively straightforward technique. It gives firm fixation and deformity correction with a smaller amount hemorrhage, less operative time and fewer complications compared to the other procedures(24). Xia L. et al inspected 89 patients who were operated with SP-osteotomy, only two had a complication, making the complication rate 2.2% which is far lower than what we unraveled. However, these operations are not directly comparable to ours due to the fact that there were no fusions. The majority of our patients who underwent SP-osteotomy also had spinal fixation of more than 3 levels as well. (25).

There are several theories to why our results are conflicting with the literature when it comes to SP-osteotomy. One of the reasons might be that SP-osteotomies were introduced when correctional surgery was new at OUS, Ullevål. The indications and techniques were improved and developed gradually with time. One can assume that this will naturally lead to a higher amount of complications in the beginning when the knowledge and experience is low. If they were to only use SP-osteotomy for less complex patients, then we believe it would amount to a far less complication rate.

The use of SP-osteotomy offers greater access to the spine. With greater access the opportunity to perform correction surgery at multiple levels arise. The aim is to achieve the most correction and balance in the spine. In contrast to if the correction is too little and the patient is left with an unbalanced spine, this can lead to failure of the fixation, pseudo arthritis, infection and pain.

Another possible reason is wrong selection of patients, surgical procedure(s) or both. Some of the patient's deformities might have developed too much and their condition was not suited for operation at all. This may have led to an extensive use of the SP-osteotomy, which resulted in the high complication rate. More knowledge and experience will in turn lead to a better selection of patients and operations techniques.

PSO

Two out of 13 patients (15%) who underwent PSO had a complication. Several studies show a high amount of complications when it comes to this procedure. Michael D. Daubs et al analyzed 65 patients who underwent PSO and looked at perioperative complications. They found a complication rate at 23%, but this included both major and minor complications, while we only focused on major complications. Hyuen SJ and Rhim SC reviewed 13 patients which resulted in a complication rate at 61%. This again included both major and minor complications. They found a 19% complication rate when it came to intraoperative complications, as well as 3 perioperative complications and 10 late-onset postoperative complications.(26-28).

Bridwell et al had a larger amount of patients with complications. They had 66 patients who underwent PSO. Early complications following the surgery was as high as 30.3%. 8% of the patients needed additional surgery due to neurological problems. After another round of decompression, none of the patients suffered from everlasting neural damage. Even though the patients had a considerable amount of complications due to the surgery, the overall improvements when it came to pain and Oswestry scores was high.(29)

TLIF

Tormenti MJ et al analyzed 531 patients who underwent a TLIF. 60% of the patients had a 1 level interbody fusion, 35% with 2 levels. They found out that 25.4% had as a minimum one surgery-related problem. They have not differentiated between major and minor complications. If we were to focus on their complications that lead to revision surgery or intervention (not medication), the complication rate was approximately at 5%. (30).

Zhang BF et al did a meta-analysis and compared TLIF versus PLF when it comes to effectiveness and danger. They found out that when it comes to VAS, ODI, reoperation and complications there were not any difference between TLIF and PLF. In the RCTs they included, they could not find TLIF increased the fusion rates in comparison to PLF. (31)

The TLIF population in this material presented a 40% complication rate amongst 10 patients. TLIF as a one or two level surgery is considered relatively safe as the studies mentioned above shows. The TLIF procedures demonstrated in this study, are adult correctional surgeries with a far higher complication rate. Burneikiene S et al looked at complications when TLIF was used in addition to posterior pedicle screw instrumentation in patients with degenerative scoliosis and spinal stenosis, a much more comparable patient population. In their study, they found a 49% complication rate when it came to the hardware and / or operational procedure. They also had a high amount of systemic complications, with one patient dying and one needing resuscitation due to cardiopulmonary arrest. Seven other patients suffered from MI, pneumonia (five) and pulmonary embolism. However, if one are to ignore the complications, the surgeries were quite successful in treating their main problem, namely the degenerative adult scoliosis. (32)

PLF

PLF was the most successful type of surgery when it came to having few complications. PLF can be combined with removing of the medial facet-joint in multiple levels and in this way gain correction from the gravitation and placement of the patient on the operation table. The best positon of the patient is to avoid any knee-elbow position, the abdomen should be free to increase the lumbar lordosis and the patient should be placed with stretched legs. This can be obtained with special pillows or surgery tables like the Jackson- or Allen table. A registry study done by Arshi A et al compared 770 patients who received PLF as outpatient with 26 826 patients who received PLF surgery as inpatients. There were a lot of complications they measured at 6 and 12 months, however, we are interested in the complication rate during surgery or as a result of the surgery. 1.10% of their patients suffered from neurological injury, which means that when it comes to neurological damage, this procedure was very safe.(33).

But the PLF surgeries performed at OUS were relatively less complex. Out of the 15 patients who received PLF, none of them were osteotomied. Also, in 73% of the cases the levels of fixations were below 5. This means that we can recommend PLF for operations where low levels of correction are needed without the need of osteotomy, but this procedure wouldn't provide a sufficient degree of correction for the majority of our patient population.

There is a lot of research going on in much older patients. Liao JC et.al found out that with accurate selection of patients, posterior decompression with instrumented fusion can not only be effective, but also less dangerous for patients that were 80 years of age or older with deteriorating lumbar disorders(34).

Revisions

We had a revision rate at 49%. This is a high number which is also found in the literature, with Kelly MP et al reporting of revision rate up to 45% (35). Several studies show that this kind of surgery is complex and often result in additional surgery with the revision percentage being 26%, 11% and 15%. As with our data, infection seemed to be a particular occurring reason for revision. One of the reason for our higher revision rate can be that our patient population is multimorbid, with not only scoliosis or kyphosis as sole reason for surgical treatment (36-38).

In terms of revisions, one can observe than men in general had more revisions at 5%. However, women in general had more multiple revisions than men. An explanation might be that the kyphotic angle in women increases faster than men after the age of 40 years. This will in turn lead to a patient needing more revisions, as the rapid increase of the kyphotic angle might lead to instability and screw loosening (39).

SP- osteotomies seem to be the primary correctional procedure most associated with revisions. It is also the most utilized technique. This procedure is usually performed at multiple levels, and as a result, the higher amount of osteotomies also carries with it a higher chance of revisions needed after the primary surgery. The SP-osteotomies has the least correction of the osteotomies, when not including PLF, but has also a lower operative risk and minimal blood loss. This might affect the choice of correctional procedure, and SP-osteotomy will be performed while the patient is in need of a correctional procedure with a higher impact. In that case, the SP-osteotomy will not be sufficient in a lasting correction, and will lead to a higher amount of revisions(40).

Pain/paralysis, screw loosening and wound infections are the common causes of revisions. SP-osteotomies have a higher incidence of revisions needed because of all of these reasons. Pain/paralysis and screw loosening are often problems that occur together, as the screw loosening leads to pain. Screw loosening in itself is a minor problem if the bone is healthy and not osteoporotic(41).

Level L3 was the level that was involved in most of the surgeries. The apex of the curvature is usually found in this level, and as a result, the correctional procedure will have more of an impact in this level. The apex ends up bearing most of the misaligned weight which will also be a cause of pain for the patient. This is seen in both scoliosis and kyphosis. L3 is also the closest level to the apex with the lowest risk of complications upon surgery compared to the other vertebrae in the vicinity. This level of the spine allows for easy access to the area of operation. Part of the reason might be that it is caudal to the conus medullaris, thus reducing the risk for major nerve damage(42).

Thoracosacral fixations have an increased revision rate compared to thoracolumbar and lumbosacral fixations. These operations are more complicated and require more time than shorter revisions. As the complexity of the operation increases, it is natural to also assume that the risk of needing a revision also does the same. This is supported in some literature, where there is a positive correlation between fixations extended to the pelvis and the need for revisions (43).

Conventional radiography

The x-ray measurements before and after operation was our most objective part of the study, however, we had our most variable parameter as well. There was no standardized protocol after the surgery. The follow-up of these patients is usually taken on how they present themselves in the post-operation consultation. As a consequence, the follow-up time with the x-rays were not strictly 12 months after their operation. The post radiographic control was also a heterogenic group, varying quite a bit because of the radiographs would be only of the part of the spine that underwent surgery. This meant that we would have a radiograph with only the lumbar, or the thoracic part, and only very rarely it was taken of the whole spine.

There are several ways to improve this issue for future studies. Firstly one could standardize the postoperation follow up to yearly controls for all patients. The radiographic work up before and after the surgery should be the same preferably a scoliosis protocol, allowing an objective validation of radiological parameters to decide whether the surgery was at least radiologically an improvement compared to the preoperative situation.

Strength and weaknesses

This study included all patients that were operated at Oslo university hospital, Ullevål in the time period 2011-2017.OUS has a nationwide function to treat these patients in Norway. This allows the inclusion of a relative high number of cases of this very complex and sophisticated type of surgery. A large amount of information was gathered about the patients, leading to many parameters being available for data collection.

A weakness is the retrospective collection of data. A prospective data collection would certainly improve the completeness of the dataset.

On the one hand the reports were written by the surgeon who performed the operation and was subject to interpretation by medical students. As a result, this might be a source of inaccurate information in terms of procedure, osteotomied levels and fixated levels as well as other parameters involving the surgery. On the other hand, the reports were analyzed by independent observers avoiding any doctor bias.

Furthermore, the pelvic parameters were measured on radiographs. In some patients, a radiologist had already taken measures. For the most part, the measurements were done separately by two students with no specific radiology training. This might be a cause of inaccurate measurements.

When comparing the preoperative and control imaging group, there is also the problem of missing data. This is due to no relevant images being available. This will lead to angles being present in some patients, while not being available in others. The cases were not differentiated in a way so only the patients where both preoperative and control angles were compared. As a result, the comparison between these groups is not completely accurate or representative for the preoperative and control imaging group.

Conclusion

We can conclude that as the complexity of the procedure increases, so does the amount of complications and revisions needed. SP-osteotomy was most frequently used and had an unusual high amount of complications. Thoraco-sacral fixated patients are at a high risk of revision, due to the nature of the complexity of this kind of operation. The rest of our results were comparable to the literature. These kinds of surgeries have a high chance of complications and revisions.

There is still much research that needs to be done in the field of spinal corrective surgery. The research demonstrates the importance of standardization both in the selection and follow-up of patients. These follow-ups should contain a consistent way of evaluating post-operational function and imaging. Further research should focus in assessing the quality of life of these patients after surgery and quality control of the surgical treatment.

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