Review

Evaluation and Rehabilitation After Adult Lumbar Spine Surgery

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Review

Evaluation and Rehabilitation after Adult Lumbar Spine Surgery

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Abstract: With an increase in proportion of elderly patients, the global burden of spinal disease is on the rise. Likewise, there has been an increasing trend in the number of spine surgeries being performed worldwide. As we know, rehabilitation following spine surgery is critical for optimal recovery. However, current literature lacks consensus regarding the appropriate post operative rehabilitation protocol. The goals of rehabilitation after lumbar spine surgery are to improve physical and psychosocial function and may include multiple modalities such as physical therapy, cognitive behavioral therapy, specialized instruments, and instruction to be followed during activities of daily living. In recent years, not only are a greater number of spine surgeries being performed, various different techniques of lumbar spine surgery and spinal fusion have emerged. Physical therapy programs need to be curated after assessing the functional status of the patient by using various patient reported outcome measures and taking into consideration the technique of spinal fusion used and the muscle groups involved in these surgeries. By doing so it is possible to assess the level of functional impairment and then specifically target strengthening of those muscle groups affected by surgery whilst also improving impaired balance and allowing return to activities of daily living. We reviewed available literature pertaining to the history of spinal rehabilitation, the popular patient reported outcome measures used and different rehabilitation methods with the purpose of summarizing the current guidelines for postoperative rehabilitation after spine surgery and to introduce the rehabilitation after lumbar surgeries that we provide at our hospital.

Keywords: Lumbar surgery; Rehabilitation; Physiotherapy; Muscle exercise

1. Introduction

Low back pain is a major cause of morbidity among middle aged and elderly individuals due to a number of possible etiologies. Even though most of the episodes of low back pain are often self-limiting, incidence of lifetime recurrence is as high as 85% [1]. Chronic low back pain not only impairs physical and psychological health but also leads to decline in social responsibilities including work performance , family life and is a major cause of increasing health care costs [2]. With advancements in medical care and increased life expectancy of the aging population, the global burden of spinal disease has increased [3].With the availability of advanced techniques such as minimally invasive spine surgery, percutaneous pedicle screw fixation, imaging and navigation, larger number of spinal surgeries are being performed nowadays with some studies documenting the number of spine surgeries to be 2.4 times of those performed 15 years ago [4,5].

Following lumbar spinal surgery, postoperative rehabilitation is crucial. It is recommended by spine surgeons for improvement of post operative functional outcome so that patients can perform their activities of daily living (ADL) at the earliest and return to work, sports, and leisure activities in the long term [6,7]. Rehabilitation programs may consist of individual training, group training, home

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exercises, patient education, or a combination of these, all led by a physical therapist. Furthermore, active rehabilitation is effective and important for improving short-term and long-term functional status [8]. Rehabilitation includes multiple different modalities based on the requirements of the patients such as providing instructions, exercise therapy such as stretching and muscle strengthening, manipulation techniques, mobilization techniques and use of assistive equipment such as walking aids [9]. When assessing the progress of post-operative patients undergoing rehabilitation, physical therapists and surgeons often have to use disease specific patient reported outcome measures and standard physical performance tests. These assessments may provide useful information regarding progress made by the patients following surgery. With different techniques of lumbar spine surgery and spinal fusion being performed, the physical therapy prescribed should be curated taking into the account the technique used and should aim to target strengthening of muscle groups violated during the surgical procedure.

The benefits of physical therapy as per literature in the past have been limited to weak evidence, and the mechanisms of these benefits remain uncertain [10,11] . This article aims to summarize the historical review of rehabilitation, popular patient reported outcome assessment methods, contemporary views on postoperative spinal rehabilitation and ways to introduce rehabilitation after lumbar spine surgery.

2. Historical Review of Rehabilitation (Table 1)

The Roman army probably provided the first rehabilitation services to return wounded soldiers to work. The word "Rehabilitation" was firstly used in the Oxford English dictionary in 1533. However, rehabilitation was used extensively in healthcare by 1918. After World War I, the society recognized rehabilitation was a crucial addition to services for injured or disabled patients [12]. Rehabilitation can be considered a planned and systematic societal support process offered to patients after injury or illness. Initially, orthopedic surgeons were mainly involved. The rehabilitation services that did develop in the twentieth century were initially focused on men of working age, who were injured in war. Because of the increase motor cycle accidents and sports injuries, attention moved to people with spinal cord injuries. Spinal cord injury rehabilitation developed 1940s as evidence of rehabilitation's revolutionary effectiveness [13]. After World Health Organization (WHO) was established in 1948, they used the biopsychosocial model as a rehabilitation frame work in 1980 [14].

For low back pain rehabilitation, lumbar stabilization exercises became popular over last 40 years. These exercises prioritize the conscious and progressive training of stabilizing muscles of the trunk [15]. Wiliams reported specific exercises known as Williams lumbar flexion exercises in 1937 [16] (Figure 1). These exercises are a series of therapeutic movements and stretches designed to activate the abdominal muscles and relax the paraspinal lumbar muscles. In 1955, Kelly addressed the importance of lumbar muscle relaxation with hanging, which is effective for lumbar foraminal enlargement, reduce muscle spasms, and facet joint release [17]. Pleasant developed and mixed Wiliams and Kelly exercises [18]. His methods consisted three concepts, which are joint mobilization, soft tissue stretching, and muscle building. Calliet reported exercise therapy positively enhanced joint capsules, ligaments, and tendons, and increased blood flow, thereby aiding in the recovery of injured regions [19]. Moreover, he emphasized resistance exercise improved muscle function by increasing the cross-sectional areas of muscles, thereby providing great benefits in prevention and treatment of pain.

Table 1. History of important lumbar exercises.

Year	Author	Rehabilitation method
1937	Williams [16]	Lumbar flexion exercises
1955	Kelly [17]	Hanging exercises
1962	Pheasant [18]	Posture building
1968	Calliet [19]	Lumbar lateral flexion exercises

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1971	Böhler [20]	Lumbar extension exercises
1979	McKenzie [21]	Lumbar extension exercises

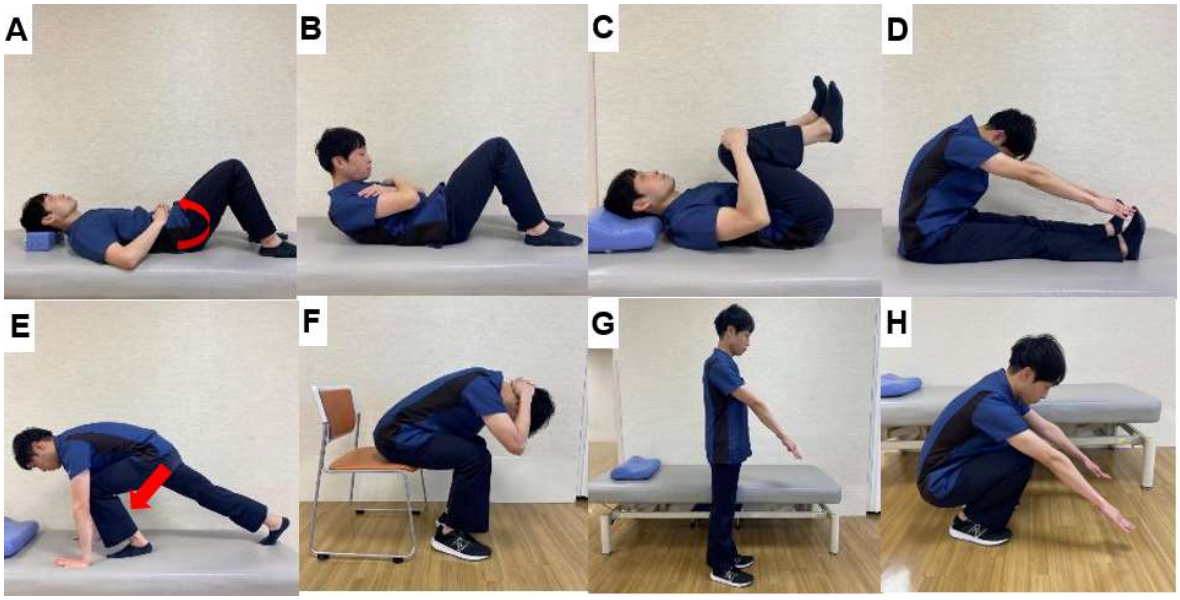

Figure 1. Williams lumbar flexion exercises, A: Pelvic tilt B: Sit-up in knee flexion C: Double knees to chest to stretch the elector spine, D: Seated reach to toes stretches the hamstrings and elector spine, E: Forward crouch to stretch iliofemoral ligament F: Seated flexion G, H: Strengthening of quadriceps muscles, and stretching of gluteus maximus and elector spine.

Compared with Williams lumbar flexion exercises, Böhler emphasized the importance of lumbar extensor muscle exercises in 1971 [20]. Then McKenzie recommended that extending the spine could provide significant pain relief to certain patients [21]. McKenzie exercises improve spinal mobility and promote good posture (Figure 2). The long-term goal of the McKenzie exercises is to teach patients suffering from back pain how to manage pain using exercise. Recently, motor control stabilization exercises are becoming popular for the patients with chronic nonspecific low back pain [22]. These exercises intended to retrain coordinated recruitment of the deep abdominal and back muscles through a submaximal voluntary isometric contraction performed in a neutral spine position. WHO has released its first-ever guidelines on managing chronic low back pain in 2023 [23]. According to this guideline, a structured exercise therapy or program and spinal manipulative therapy may be offered as part of care to adults, including older people, with chronic primary low back pain.

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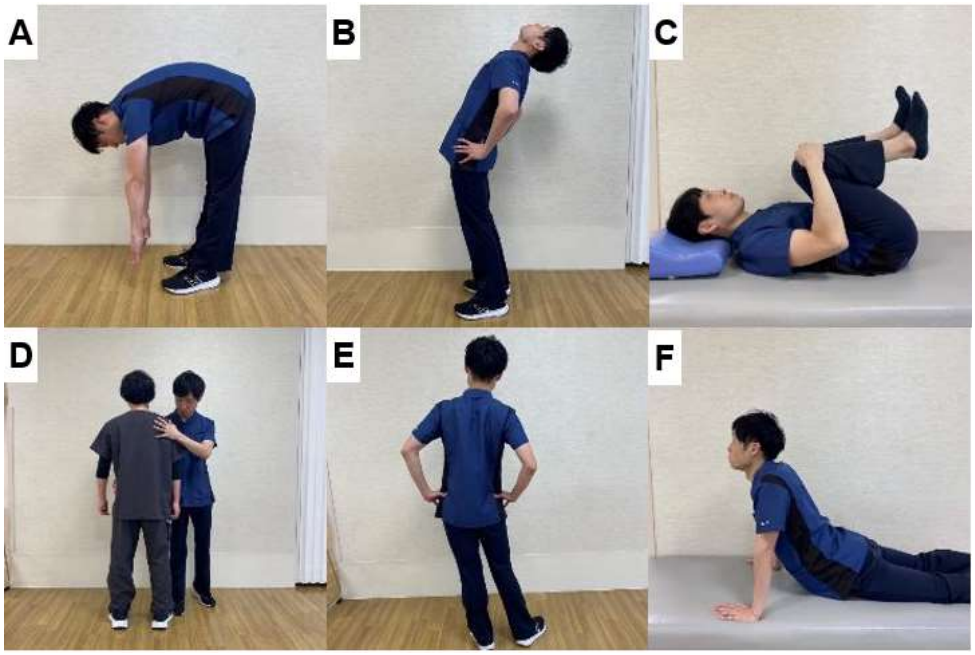

Figure 2. McKenzie exercises, A: Flexion in standing B: Extension in standing C: Flexion in lying, D: Therapist assisted side glide in standing E: Side glide in standing F: Extension in lying.

3. Various Kinds of Rehabilitation

Postsurgical rehabilitation interventions include therapy, which aims to improve function through the diagnosis and treatment of health conditions, reducing impairments, preventing, or treating complications. Furthermore, rehabilitations restore and compensate for loss of functioning, and prevent or slow deterioration in functioning in every area of a person's life [24]. Rehabilitation may also include assistive technology, which refers to equipment, or product used to increase, maintain, or improve functional capabilities [24]. Postsurgical rehabilitation can be provided by different healthcare providers including, but not limited to, general practitioners, orthopedic surgeons, physiotherapists, chiropractors, and occupational therapists. Examples of postsurgical rehabilitation interventions are showed in Table 2.

Table 2. Example of selected interventions for rehabilitation after lumbar surgery.

Intervention	Definition	Example
Patient education and self-management [9]	Teaching patient's skills that they can use to manage their health condition	How to deal with pain The importance of physical activity in pain reduction Restrictions and working posture postoperatively (ergonomics) Coping with pain flare-ups How to return to work and cope with physical, social, and other barriers
Early Exercise [25]	A subcategory of physical activity that is planned, structured, repetitive, and purposeful; can be supervised (eg, by a healthcare professional) or unsupervised	Stretching, Muscle strengthening Endurance exercises Neuromuscular closed chain exercises Range of motion exercise

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Manual therapies [26,27]	Myofascial release: Technique that applies low-impact, prolonged stretching to the fascial complex to restore optimal length of fascial tissue, decrease pain, and improve functionality. Neural mobilization: A technique that stretches damaged nerves and improves their glide and extensibility. Manipulation: techniques incorporating a high-velocity low-amplitude impulse or thrust applied at or near the end of a joint's passive range of motion Mobilization: techniques incorporating a low-velocity and small or large amplitude oscillatory movement, within a joint's passive range of motion	Myofascial release Neural mobilization Massage Lumbar manipulation, mobilization
Assistive technologies	Any item, piece of equipment or product system, used to increase, maintain, or improve the functional capabilities of people with disabilities	Walking aids Socks aids Pants aids Shoehorn Reacher

4. Patients Reported Outcome (PRO) Measures Used after Lumbar Surgery

PRO is useful to evaluate the various symptoms of spinal disease separately, it is possible to accurately assess the disability caused by the disease by including the impact of the spinal disease on daily life. It is necessary to use PRO to assess the impact on physical function, ADL, and quality of life. (QOL) These patients reported outcome questionnaires are frequently used by spine surgeons and physical therapists to assess the functional outcome of patients following spinal surgery. Jaeschke et al proposed the term minimal clinically important difference (MCID) (Figure 3) [28]. The minimal detectable change (MDC) was estimated by means of the standard error of measurement in patients who self-assess as unchanged. The MCID describes the smallest clinical difference a patient can perceive in a specific questionnaire of data study.

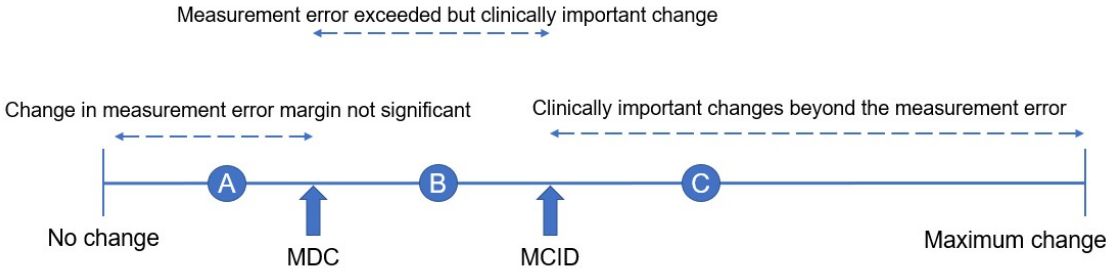

Figure 3. Interpretation of changes in post-treatment evaluation results, A: Post-treatment evaluation results are measurement error and clinically not important., B: The post-treatment assessment results showed changes beyond the measurement error, but not clinically important changes., C: The results of the post-treatment evaluation show clinically important changes.

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Acknowledging the relevance of such an approach, additional clinically oriented concepts have been introduced which can be used to better interpret PRO measures data. The MCID is relative to the initial symptomatic state before treatment. A helpful concept to rate a cohort's condition in absolute terms is the patient-acceptable symptom state, defined as the value on a PRO scale beyond which patients with a specific condition consider themselves well or in a satisfactory state [29]. Using all these parameters in the interpretation of evaluation outcomes, a better and patient-oriented description of obtained success rates in therapeutic approaches can be provided. A systematic review of postoperative MCID for lumbar spine disease has been reported by Issa et al.[30] The reported MCID after surgery for lumbar spine disease is shown (Table 2).

Table 3. MCID in PRO after surgery for lumbar spine disease.

Study	PRO	Recommended MCID	Procedure	Diagnosis
Parker [31]	ODI	14.9	TLIF	Lumber degenerative spondylolisthesis
	VAS Back	2.1		
	VAS Leg	2.8		
Parker [32]	ODI	4	Lumbar fusion	Pseudarthrosis
	VAS Back	3		
Johnsen [33]	ODI	12.88	Disk replacement	Degenerative disease
Solberg [34]	ODI	20	Discectomy	Lumbar disk herniation
	NRS Back	2.5		
	NRS Leg	3.5		
Yoshida [35]	ODI	11	Posterior corrective spinal fusion surgery	Adult spinal deformity
Fukushima [36]	ZCQ SSS	1.0	Microendoscopic laminectomy	Lumbar spinal stenosis
	ZCQ PFS	0.6		

2.1. Roland-Morris Disability Questionnaire (RMDQ) (Figure 4)

The RMDQ is the most commonly used lumber spine-specific assessment method [37].

Problems with the RMDQ include the lack of questions related to mental health and the fact that it is difficult for patients with only leg pain to answer [38].

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Roland-Morris Low back pain and Disability Questionnaire (RMDQ)

Instructions

Patient name:_____ File #:_____ Date:_____

Please read instructions: When your back hurts, you may find it difficult to do some of the things you normally do. Mark only the sentences that describe you today.

- ☐ I stay at home most of the time because of my back.
- ☐ I change position frequently to try to get my back comfortable.
- ☐ I walk more slowly than usual because of my back.
- ☐ Because of my back, I am not doing any jobs that I usually do around the house.
- ☐ Because of my back, I use a handrail to get upstairs.
- ☐ Because of my back, I lie down to rest more often.
- ☐ Because of my back, I have to hold on to something to get out of an easy chair.
- ☐ Because of my back, I try to get other people to do things for me.
- ☐ I get dressed more slowly than usual because of my back.
- ☐ I only stand up for short periods of time because of my back.
- ☐ Because of my back, I try not to bend or kneel down.
- ☐ I find it difficult to get out of a chair because of my back.
- ☐ My back is painful almost all of the time.
- ☐ I find it difficult to turn over in bed because of my back.
- ☐ My appetite is not very good because of my back.
- ☐ I have trouble putting on my socks (or stockings) because of the pain in my back.
- ☐ I can only walk short distances because of my back pain.
- ☐ I sleep less well because of my back.
- ☐ Because of my back pain, I get dressed with the help of someone else.
- ☐ I sit down for most of the day because of my back.
- ☐ I avoid heavy jobs around the house because of my back.
- ☐ Because of back pain, I am more irritable and bad tempered with people than usual.
- ☐ Because of my back, I go upstairs more slowly than usual.
- ☐ I stay in bed most of the time because of my back.

Figure 4. Roland-Morris Low back pain and Disability Questionnaire (RMDQ).

2.2. Oswestry Disability Index (ODI) (Figure 5)

The ODI was initially published by Fairbank to measure disability in daily living associated with low back pain [39,40]. Score 0-4; No disability, 5-14; Mild disability, 15-24; Moderate disability, 25-34; Severe disability, 35-50; Complete disability. ODI can evaluate ADL impairment due to low back pain and the influence of lower limb pain and is correlated with lower limb pain before and after surgery [41]. ODI is more sensitive to change than more general health measures, when tracking the effectiveness of treatments [42].

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Oswestry Disability Index Questionnaire (ODI)

1. PAIN INTENSITY
- ☐ I can tolerate the pain I have without having to use pain killers
- ☐ The pain is bad but I manage without taking pain killers
- ☐ Pain killers give complete relief from pain
- ☐ Pain killers give moderate relief from pain
- ☐ Pain killers give very little relief from pain
- ☐ Pain killers have no effect on the pain and I do not use them

2. PERSONAL CARE (e.g. Washing, Dressing)
- ☐ I can look after myself normally without causing extra pain
- ☐ I can look after myself normally but it causes extra pain
- ☐ It is painful to look after myself and I am slow and careful
- ☐ I need some help but manage most of my personal care
- ☐ I need help every day in most aspects of self care
- ☐ I don't get dressed, I was with difficulty and stay in bed

3. LIFTING
- ☐ I can lift heavy weights without extra pain
- ☐ I can lift heavy weights but it gives extra pain
- ☐ Pain prevents me from lifting heavy weights off the floor, but I can manage if they are conveniently positioned, i.e. on a table
- ☐ Pain prevents me from lifting heavy weights, but I can manage light to medium weights if they are conveniently positioned
- ☐ I can lift very light weights
- ☐ I cannot lift or carry anything at all

4. WALKING
- ☐ Pain does not prevent me walking any distance
- ☐ Pain prevents me walking more than one mile
- ☐ Pain prevents me walking more than ½ mile
- ☐ Pain prevents me walking more than ¼ mile
- ☐ I can only walk using a stick or crutches
- ☐ I am in bed most of the time and have to crawl to the toilet

5. SITTING
- ☐ I can sit in any chair as long as I like
- ☐ I can only sit in my favorite chair as long as I like
- ☐ Pain prevents me from sitting more than one hour
- ☐ Pain prevents me from sitting more than ½ hour
- ☐ Pain prevents me from sitting more than 10 minutes
- ☐ Pain prevents me from sitting at all

6. STANDING
- ☐ I can stand as long as I want without extra pain
- ☐ I can stand as long as I want but it gives me extra pain
- ☐ Pain prevents me from standing for more than one hour
- ☐ Pain prevents me from standing for more than 30 minutes
- ☐ Pain prevents me from standing for more than 10 minutes
- ☐ Pain prevents me from standing at all

7. SLEEPING
- ☐ Pain does not prevent me from sleeping well
- ☐ I can sleep well only by using medication
- ☐ Even when I take medication, I have less than 6 hrs sleep
- ☐ Even when I take medication, I have less than 4 hrs sleep
- ☐ Even when I take medication, I have less than 2 hrs sleep
- ☐ Pain prevents me from sleeping at all

8. SOCIAL LIFE
- ☐ My social life is normal and gives me no extra pain
- ☐ My social life is normal but increases the degree of pain
- ☐ Pain has no significant effect on my social life apart from limiting my more energetic interests, i.e. dancing, etc.
- ☐ Pain has restricted my social life and I do not go out as often
- ☐ Pain has restricted my social life to my home
- ☐ I have no social life because of pain

9. TRAVELLING
- ☐ I can travel anywhere without extra pain
- ☐ I can travel anywhere but it gives me extra pain
- ☐ Pain is bad, but I manage journeys over 2 hours
- ☐ Pain restricts me to journeys of less than 1 hour
- ☐ Pain restricts me to short necessary journeys under 30 minutes
- ☐ Pain prevents me from traveling except to the doctor or hospital

10. EMPLOYMENT/ HOMEMAKING
- ☐ My normal homemaking/ job activities do not cause pain.
- ☐ My normal homemaking/ job activities increase my pain, but I can still perform all that is required of me.
- ☐ I can perform most of my homemaking/ job duties, but pain prevents me from performing more physically stressful activities (e.g. lifting, vacuuming)
- ☐ Pain prevents me from doing anything but light duties.
- ☐ Pain prevents me from doing even light duties.
- ☐ Pain prevents me from performing any job or homemaking chores.

Figure 5. Oswestry Disability Index.

2.2. Zurich Claudication Questionnaire (ZCQ)

The ZCQ is a disease-specific assessment of lumbar spinal stenosis (LSS) and is assessed in three domains: symptom severity, functional impairment, and treatment satisfaction [43]. The ZCQ demonstrates good validity and reliability in patients with LSS and is recommended as one of the appropriate methods for evaluating LSS treatment outcomes [44].

2.3. Scoliosis Research Society 22-Item Questionnaire (SRS-22)

The SRS-22 is used to assess QOL and surgical outcomes in an array of different spinal deformities [45,46]. It consists of 22 questions covering four domains: pain, functioning, self-image, and satisfaction with the surgery [47]. The SRS-22 is a valid and reliable tool that has been extensively studied [48]. Markers of sagittal balance, such as the sagittal vertical axis, have a significant correlation with all SRS domains, and pelvic tilt, which describes the orientation of the pelvis in

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relation to the body, has demonstrated correlation with SRS-22 in function and self-image domains [49,50].

2.4. Lumbar Stiffness Disability Index (LSDI)

The LSDI was designed and validated as a tool to assess functional impacts of lumbar spine stiffness and diminished spinal flexibility [51–53]. It is particularly used to evaluate patients after spinal fusion surgery, and it has been shown that LSDI worsens and postoperative satisfaction decreases in surgeries that involve a long fusion [54,55].

5. Physical Performance Tests

The prevalence of lumbar canal stenosis increases with age and is the most common diagnosis in patients over age 65 undergoing spinal surgery [56–58]. Older patients with lumbar spine disease have locomotive syndrome and reduced physical function [59–61]. Therefore, it is important, especially in the rehabilitation field, to assess physical function to aid in the planning of a program of therapeutic interventions. Minimal clinically important difference (MCID) has been reported in physical function assessment as well as in PRO. In general, the following assessments of physical function are used.

5.1. Walk Velocity (Figure 6)

Walk velocity is a performance measure used to assess walking speed in meters per second over a short distance [62]. A decrease in walking speed is defined as walking velocity of 0.8 m/s or less [63]. Changes in postoperative pain after lumbar spine surgery are associated with gait speed. Gait speed is therefore a necessary assessment for the management of pain and disability in patients after lumbar spine surgery [64]. MCID of walk velocity after ASD surgery is 0.1m/S [65].

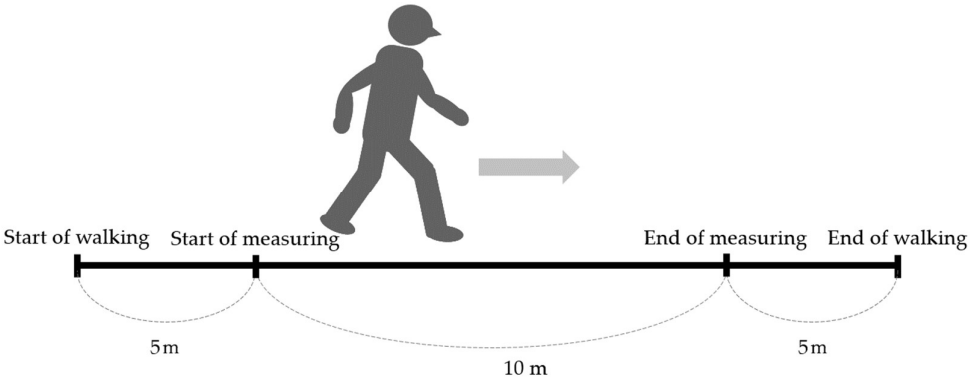

Figure 6. Walk velocity.

5.2 6-Minute Walk Test (Figure 6)

6-minute walk test involves walking for 6 minutes on a 30m walking path and measuring the distance [66]. Six-minute walking distance is used to evaluate walking efficiency in patients with neurogenic claudication in LSS and ASD [67,68]. Self-reported walking distance in LSS patients underestimates measured walking distance by 31% and has low validity [69]. Therefore, when comparing the improvement of intermittent claudication after treatment, it is desirable to evaluate the actual walking distance using the 6-minute walk test. MCID of 6-minute walk distance after LSS surgery is 57.5m [70].

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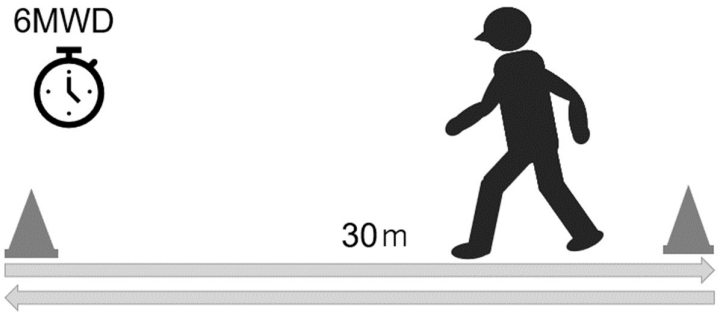

Figure 7. 6-Minute walk test.

5.3. Timed Up and Go Test (TUG) (Figure 7)

The timed up and go test (TUG) is an objective measure of functional disability that can be used to evaluate various activities such as standing, accelerating, walking, decelerating, and turning, which are often limited in patients with lumbar degenerative diseases [71]. TUG can be easily done with a chair and a 3-m walking space and does not require special equipment [72]. A previous study used TUG to measure motor impairment in patients with lumbar degenerative diseases, with < 11.5 s classified as no impairment, 11.5 to 13.4 s as mild impairment, 13.4 to 18.4 s as moderate impairment, and > 18.4 s as severe impairment [71]. TUG is not easily affected by the patient's mental state, lifestyle, or physique [73,74] and is highly related to factors of daily life functions such as lower limb muscle strength, sense of balance, walking ability, and risk of falling [66]. Furthermore, the TUG is used to evaluate motor function in a wide range of subjects, from healthy patients to those with lumbar degenerative diseases [74,75]. Therefore, TUG is useful for evaluating dynamic balance in lumbar spine diseases. The MCID of TUG after ASD surgery and lumbar degenerative disease surgery is reported to be 2.0 sec [65] and 2.1 sec [76], respectively.

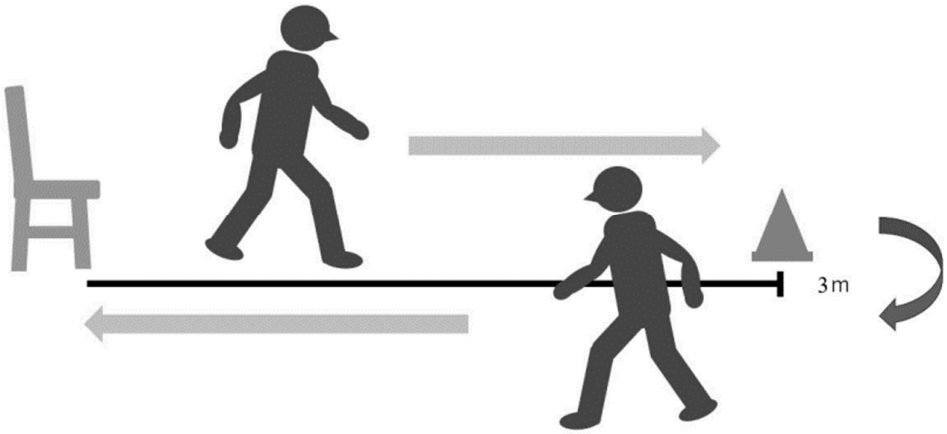

Figure 7. Timed up and go test.

5.5. Functional Reach Test (FRT) (Figure 8)

The FRT quantifies participants' dynamic in-place standing balance control as reach distance. The distance between the starting and maximal forward reach distance beyond the participant's arm length represents the reach distance and is recorded in centimeters [77]. Spinal mobility has been shown to significantly impact distance reached [78]. Performance of the FRT involves trunk control and depends on back muscle endurance and strength [79,80]. Injury to paraspinal muscles and changes in proprioception of paraspinal muscles due to lumbar spine surgery affect trunk muscle strength, leading to decreased trunk control and postural instability [81], so balance assessment using FRT is necessary.

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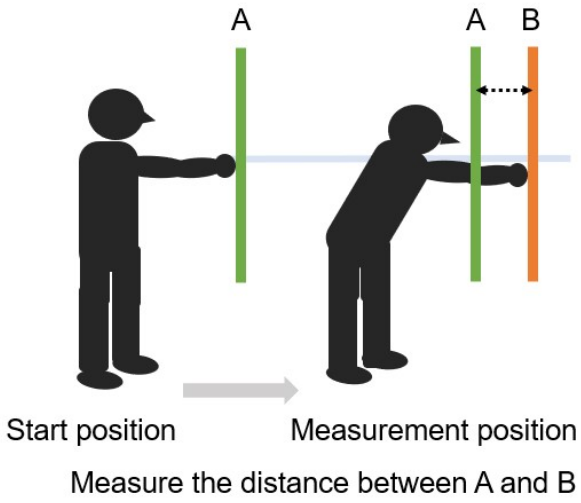

Figure 8. Functional Reach Test.

5.6. The Balance Evaluation Systems Test (BESTest) (Table 4)

The BESTest is a functionality scale developed to assess balance and risk of falls in the elderly [82]. It consists of 36 items and is grouped into six subsections, which represent different systems that may constrain balance, namely **A:** biomechanical constraints, **B:** stability limits/verticality, **C:** anticipatory postural adjustments, **D:** postural responses, **E:** sensory orientation, and **F:** stability in gait. Each item is scored on a four-point ordinal scale from 0 (worst performance) to 3 (best performance). Total and subscale scores are translated to a percentage score. The BESTest influences QOL in ASD [83], and the reliability of the BESTest has been reported [84]. BESTest is difficult to use in clinical practice due to its complexity, so a shortened version called Mini-BESTest [85] has been developed (Table 5).

Table 4. BESTest.

I. Biomechanical constraints	II. Stability limits	III. Anticipatory Postural Adjustments	IV. Postural Responses	V. Sensory orientation	VI. Stability in gait
1. Base of support	6. Sitting verticality (left and right) and lateral lean	9. Sit to stand	14.In-place response, forward	19. Sensory integration for balance, Stance on firm surface,	21. Gait level surface
2. CoM alignment	7. Functional reach forward	10.Rise to toes	15. In-place response, backward	20. Incline, EC	22. Change in gait speed
3. Ankle strength and ROM	8. Functional reach lateral	11. Stand on one leg	16. Compensatory stepping correction, forward		23. Walk with head turns, horizontal

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4. Hip/trunk lateral strength		12. Alternate stair touching	17. Compensatory stepping correction, backward		24. Walk with pivot turns
5. Sit on floor and stand up		13. Standing arm raise	18. Compensatory stepping correction, lateral		25. Step over obstacles
					26. Timed "Get Up & Go" Test
					27. Timed "Get Up & Go" Test with dual task

CoM=center of mass, ROM=range of motion, CTSIB=Clinical Test of Sensory Integration for Balance, EO=eyes open, EC=eyes closed.

Table 5. Mini Balance Evaluation Systems Test (Mini BESTest).

Anticipatory Postural Adjustments	Postural Responses	Sensory Orientation	Dynamic Gait
1. Sit to stand	4. Compensatory stepping correction, forward	7. Stance on firm surface, EO	11. Change in gait speed
2.Rise to toes	5. Compensatory stepping correction, backward	9. Stance on foam, EC	12. Walk with head turns, horizontal
3. Stand on one leg (left and right)	6. Compensatory stepping correction, lateral (left and right)	10. Incline, EC	13. Walk with pivot turns
			12. Step over obstacles
			14. Cognitive Get up and Go

EO= Eyes Open; EC= Eyes Closed.

5.73. D Motion Analyzers and Force Plate

Usually, gait analysis is generally performed with 3D motion analyzers [86,87] and force plates [88,89]. These devices can be used to analyze gait patterns, detailed joint movements, and gravity lines [90,90]. However, the disadvantages of these methods are cost-effectiveness, complexity of equipment operation and analysis process.

5.8. Triaxial Accelerometer (Figure 9)

Gait sway evaluation using an accelerometer (wearable sensor) has become a popular gait evaluation method due to its cost-effectiveness [92–94]. Accelerometers are easy to wear and have no limitations on measurement location, making them simple and practical tools in clinical practice [95]. Root mean square (RMS) of trunk acceleration has been used as one of the indicators of gait sway using accelerometers [96]. RMS represents the degree of amplitude of the waveform, and a larger trunk acceleration RMS during gait indicates a greater gait sway.

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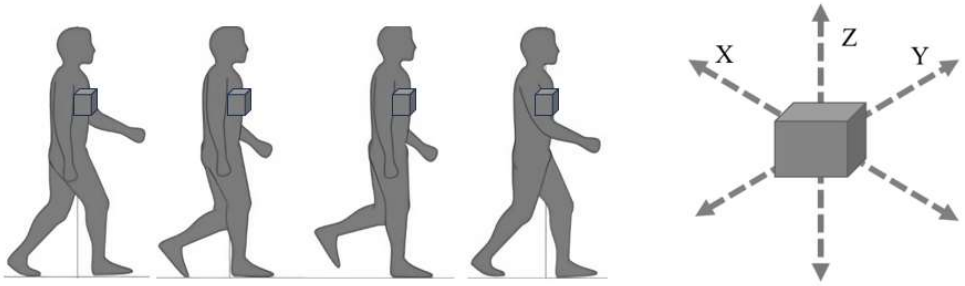

Figure 9. The principle of accelerometer.

6. Physical Therapy after Lumbar Spine Surgery

We believe that postoperative physical therapy after lumbar spine surgery is important to strengthen the affected muscles, improve balance, and facilitate return to ADL. Spinal surgery mainly includes decompression and fusion, with good postoperative results regardless of the surgical technique, and in recent years, multi-level fusion has become increasingly common [58,97]. A comparison of surgical techniques, fixation is more invasive than decompression in terms of blood loss, operative time, and length of hospital stay [98,99].

In recent years, lateral lumbar interbody fusion (LLIF) has become more popular, with extreme lateral interbody fusion (XLIF) and oblique lumbar interbody fusion (OLIF) being the most common LLIF techniques. These techniques are less invasive than the conventional posterior lumbar interbody fusion (PLIF) [100] and transforaminal lumber interbody fusion (TLIF) [101] and allows for the insertion of a larger cage, which allows for a greater restoration of lumbar lordosis [102,103].

In physical therapy, it is necessary to identify the path of entry for spinal fusion and to understand the muscles involved [104] (Figure 10). Muscle atrophy results from denervation due to surgical invasion of the multifidus and erector spinae muscles for posterior approach (PLIF and TLIF) [105,106]. LLIF incises the external oblique, internal oblique, and transversus abdominis muscles, resulting in postoperative muscle weakness (Figure 11). Hence rehabilitation should be focused according to the procedure performed as trunk extension and trunk flexion strength strongly correlate with ODI [107].

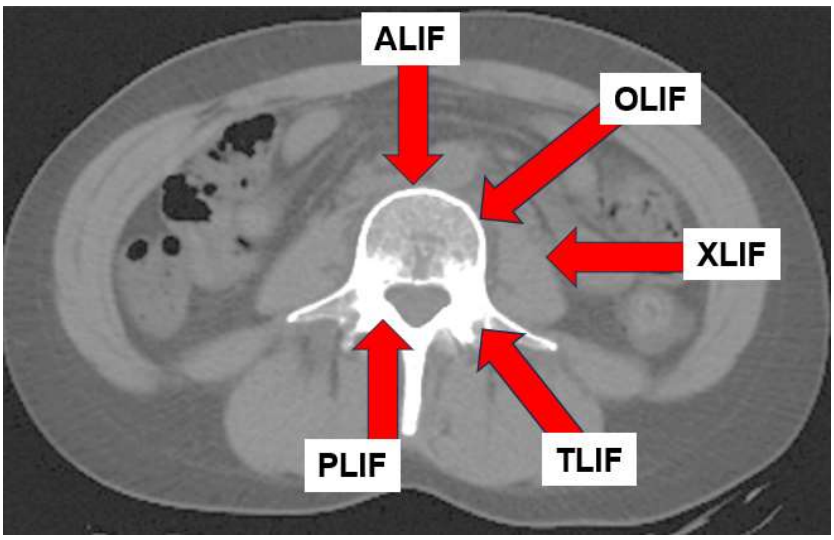

Figure 10. The path of entry for different spinal fusion techniques.

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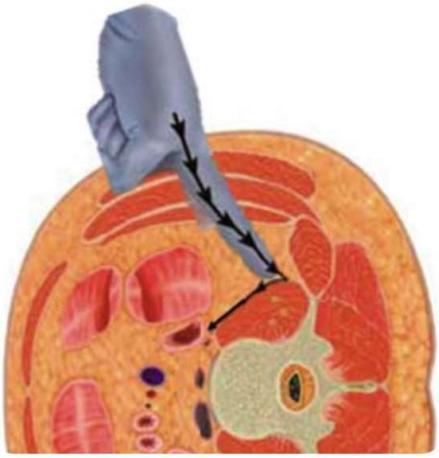

Figure 11. Oblique lumbar interbody fusion (OLIF) approach.

6.1. Trunk Muscle Strengthening (Figure 12)

After lumbar spine fusion, motion at the level adjacent to the fusion may be altered to compensate for changes caused by the fusion, an occurrence that must also be taken into account when planning postoperative rehabilitation programs. During the early postoperative phase, strengthening exercises should be performed while keeping the lumbar spine in a neutral position to minimize strain on the fused/adjacent segment and thereafter to avoid breakage or pull out of the implants. In functional neutral spine control exercises (NSCE, **Figure 3**), a destabilizing force acts on the trunk through loading of the extremities, and therefore proper recruitment of the trunk muscles is required to stabilize the lumbo-pelvic complex [108].

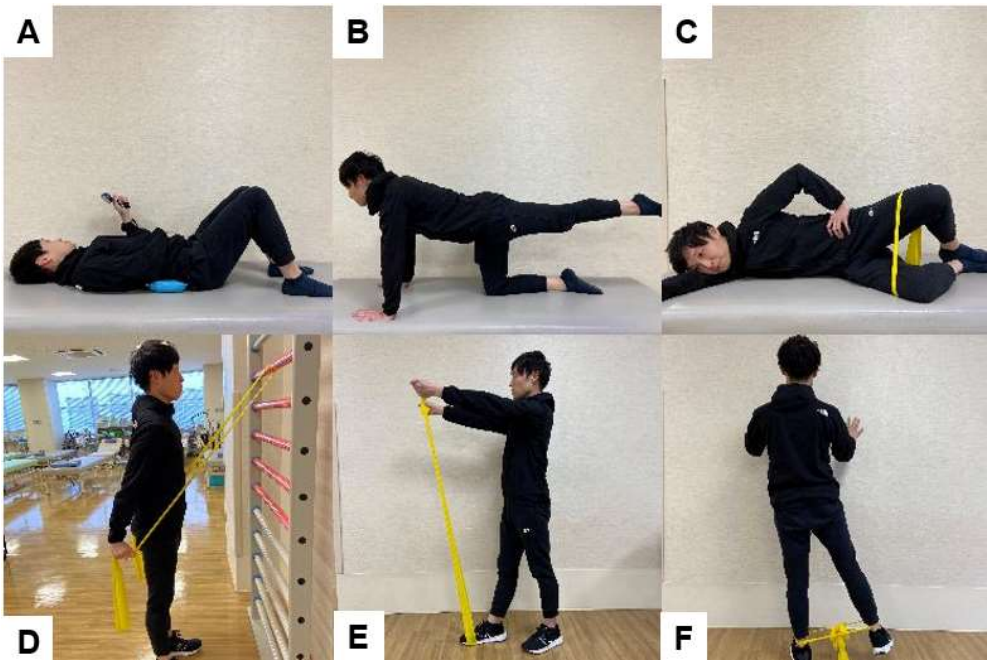

Figure 12. Functional neutral spine control exercises, A: Drow-in [109,110], B: Bird dog exercise, C: Clam shell exercise, D: Bilateral shoulder extension, E: Bilateral shoulder flexion, F: Hip abduction.

Functional NSCE mimic the trunk muscle activity patterns that occur during activities of daily life, such as lifting, pushing, or pulling movements [111,112]. The NSCE program has two main aims: (i) to improve control of the neutral lumbar spine position and (ii) to increase trunk and hip muscle coordination, strength, and endurance [113]. Figure 3 shows the NSCE we have been using since the acute phase.

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6.2. Psoas Muscle Strengthening

In XLIF, the disc space is approached through the psoas muscle. XLIF splits the psoas major muscle, resulting in muscle weakness at a rate of 9% to 31% [114]. OLIF avoids splitting of the psoas major muscle, but is still associated with a 1.2% incidence of psoas muscle weakness [115]. Corrective spinal fusion for ASD with OLIF has also been shown to decrease psoas major muscle strength [116]. Strength of the psoas major muscle is related to postoperative gait sway after ASD correction [86] and to the rate of bony fusion [117] making postoperative strengthening of the psoas major muscle an important part of physical therapy programs.

There are some points to keep in mind when strengthening the psoas major muscle after lumbar fusion surgery. The psoas major muscle has a lumbar extension function in lumbar lordosis and a lumbar flexion function in lumbar kyphosis (Figure 13) [118]. Lumbar kyphosis is a factor in impairment of ADL and adjacent segment diseases [119,120]. Hence, it is necessary to strengthen the psoas major muscles in a posture that can maintain the physiological lordotic position of the lumbar spine. The exercises we perform at our clinic to strengthen the psoas major muscles are shown in Figure 14.

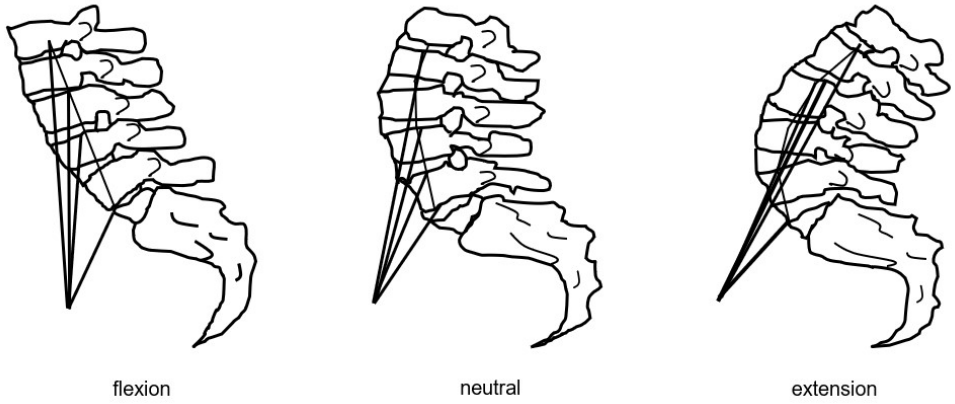

Figure 13. Effect of iliopsoas muscle in three positions.

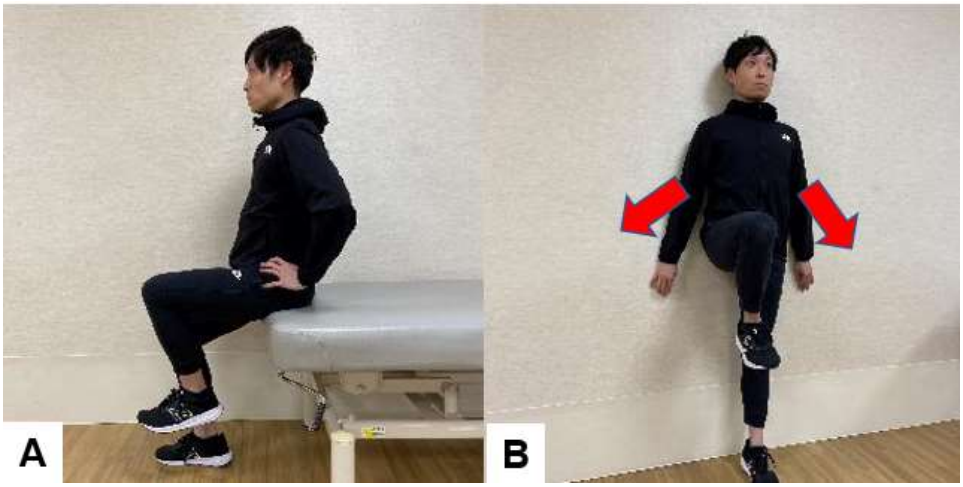

Figure 14. Iliopsoas muscle exercise, A: Hip flexion exercise in sitting position , B: Wall Standing exercise.

6.3. Exercises to Improve Balance after Spinal Fusion Surgery

Balance dysfunction can occur after spinal surgery, increasing the risk of falls and hip fractures. Patients with long-segment thoracolumbar spine fusions had a significantly higher risk of hip fracture than those with only discectomies [121]. After a spinal fusion, ASD patients exhibit altered proprioception, sensorimotor integration failure, and postural reflex dysfunction [122]. In ASD

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patients after corrective spinal fusion, dynamic balance capacity improves after 6 months postoperatively [123] and is related to achieving the patient-acceptable symptom state in ODI [124]. In recent years, BESTest has been used to evaluate balance ability in ASD [83,84].

It has been reported that patients with ASD have poorer BESTest results and reduced dynamic balance than healthy elderly people [83]. Halvarsson's program includes five of the six domains of this model [125] (Figure 15). Training balance during dual-task conditions appears to be necessary to improve balance control under situations with divided attention, as balance training with single-task exercises have shown to not transfer to dual-task performance [126].

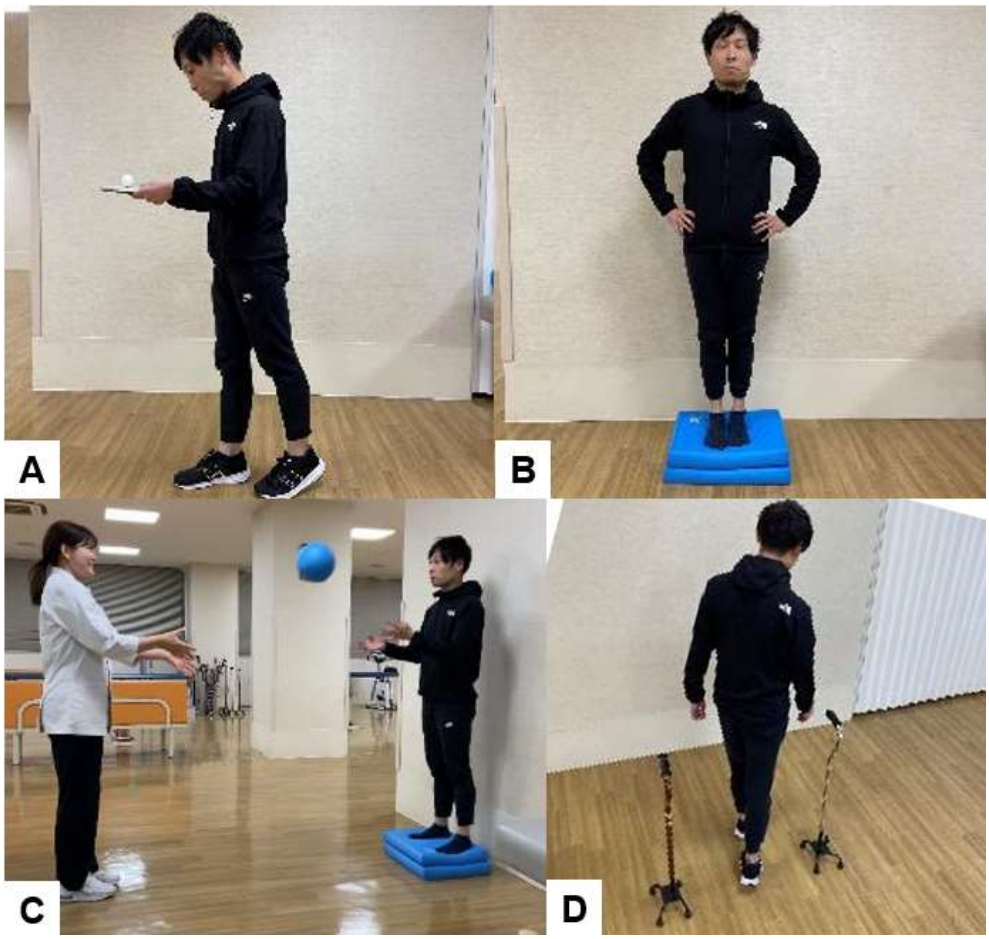

Figure 15. Dual and multitask balance exercise, A: Walk while trying not to drop the ball on the tray B: Stand on balance cushions with eyes closed, C: Catch the ball while standing on the balance cushion, D: Slalom walking with additional cognitive tasks.

6.4. Guidance on ADL after Spinal Fusion Surgery

Patients who underwent a multilevel fusion, especially more than 4 levels, reported more limitations because of postoperative lumbar stiffness [127]. Patients with ASD after spinal corrective fusion surgery have difficulty with activities such as picking up objects from the floor, cutting toenails, maintaining personal hygiene, and putting on pants, even 2 years after surgery [128]. Lumbar spinal fusion patients with a fixed pelvis should be taught the use of self-help devices and ADL to prevent implant failure (Figure 16).

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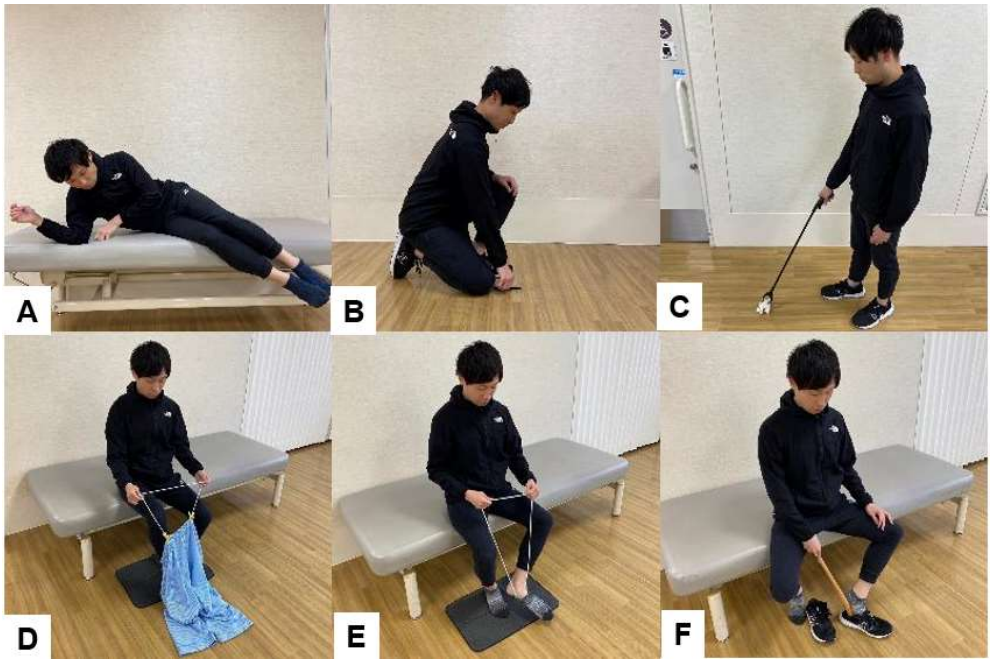

Figure 16. Self-help devices and coaching of ADL, A: Getting up from lateral position, B: Pick up things from the floor , C: How to pick up objects from the floor using self-help tools, D: How to put on pants using a trouser aid, E: How to put on pants using a trouser aid, F: How to put on shoes using a shoehorn.

Rohlmann et al. reported movements and exercise therapy that place stress on the spine in patients undergoing lumbar corpectomy [129,130]. Movements that place stress on the spine include lifting a weight from the ground, forward elevation of straight arms with a weight in hands, tying shoes, and forward bending [129]. After lumbar spinal fusion, it is necessary to teach patients to avoid these behaviors. The exercise therapy that places stress on the spine should be avoided until bony fusion. These exercises include lifting both legs in the supine position, lifting the pelvis in the supine position, outstretching one arm with or without simultaneously outstretching the contralateral leg in the all-fours position, and arching the back in the all-fours position (Figure 17) [130].

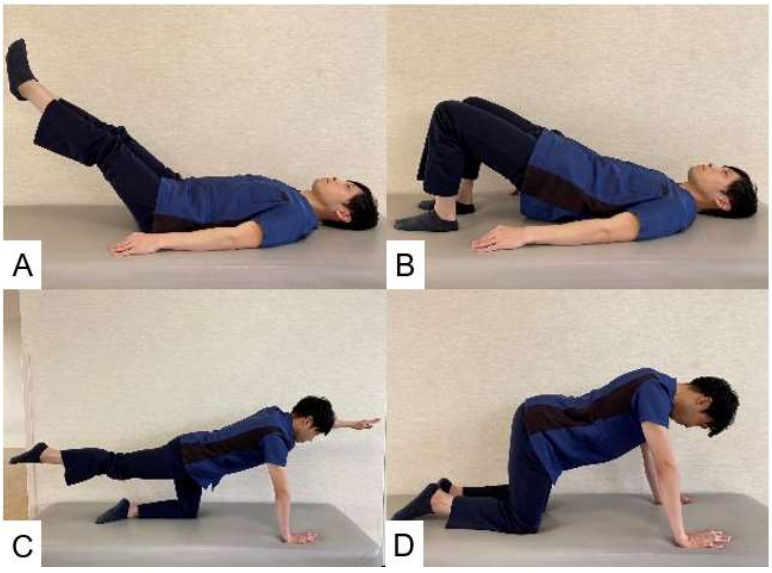

Figure 17. The restricted exercise, A: Lifting both legs in the supine position ,B: Lifting the pelvis in the supine position, C: Outstretching one arm with or without simultaneously outstretching the contralateral leg in the all-fours position, D: Arching the back in the all-fours position.

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5. Conclusions

The purpose of rehabilitation after lumbar spine surgery is to improve physical and psychosocial function, prevent and treat complications, and mitigate residual symptoms. Physical therapy, cognitive-behavioral therapy, and ADL are used to assess lumbar spine disease using PROs and physical performance tests.

The evaluation of lumbar spine disease requires a detailed understanding of the patient's problems using PROs and physical performance tests. In particular, in rehabilitation after lumbar fusion surgery, it is important to strengthen the abdominal muscles, back muscles, and psoas muscles to improve muscle strength that has decreased due to the surgical invasion, and to perform functional neutral spine control exercises to reduce the risk of falling. In addition, compensatory movements involving trunk strengthening exercises and the use of self-help devices should be taught to reduce the burden on the implants and adjacent vertebrae.

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