**A Review on the Assessment of Spinal Alignment based on a Modified Sagittal Spine Postural Classification**

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**Abstract.** In the medical domain, it is imperative to accurately document spinal angle and morphology in both the frontal and sagittal planes while evaluating spinal alignment. Numerous diagnostic procedures have been developed to test the spinal column's mobility, functioning, and curvatures. Various techniques employed in this field encompass the utilization of tools such as the goniometer, spondylometer, scoliometer, kyphometer, and digital inclinometer, as well as imaging modalities like X-ray and CT scans, MRI, and US . However, most of these methods demonstrate either a limited degree of precision or reliability, as well as significant costs and potential risks related to radiation exposure for the patient. This article comprehensively evaluates numerous studies and research that have examined the validity and reliability of the spinal mouse device (SM) as a portable, radiation-free, non-invasive, and user-friendly instrument. Additionally, the examination with this device is conducted efficiently within a short timeframe. The present research study relies on a range of prior investigations conducted between 2012 and 2023 to evaluate the effectiveness of the SM to assess spine curvatures, movement, and functionality.

***Keywords:***

***Spinal curvature, Scoliosis, SM, Validity, Reliability.***

# INTRODUCTION:

The spinal column is the human body's central axis of the skeletal system. It comprises five regions: cervical, thoracic, lumbar, sacral, and coccygeal [1]. In addition to the primary and secondary curvatures exhibited in the sagittal plane, the spinal column may show a modest degree of curvature in the coronal plane. Scoliosis is a condition characterized by a sideways curve that is equal to or greater than 10 degrees [2]. Scoliosis is a condition where a person's spine is abnormally curved from side to side. The spinal column displays a complex spiral structure with abnormalities occurring in all three anatomical planes [3]. Numerous techniques have been developed to assess the spinal column's mobility and functionality and evaluate its curvatures for individuals with scoliosis. These include instruments involving a goniometer [4], spondylometer[5], scoliometer, kyphometer [6],digital inclinometer [7], flexible curve ruller [7], fingertip-to-floor distance measurement [8], tape-measurement-method [4], and the Schober-index [9]. One disadvantage of these methodologies is the challenge of accurately identifying specific anatomical signs, such as the lumbosacral junction and the Venus dimples. Other issues are the need for more proof about the reliability and accuracy of the metric measurements used to determine lumbar spine mobility and their sensitivity to variation [10]. X-ray and computed tomography (CT) scans are imaging techniques that offer enhanced precision. Imaging methods in clinical investigations to examine spinal flexibility and assess patients' preoperative or postoperative conditions is an increasingly prevalent trend [11]. However, radiation possesses both deterministic and stochastic biological consequences, with the latter characterised by cumulative tendencies and encompassing cancer development [12]. Furthermore, one spinal curve—cervical, thoracic, or lumbar—may be evaluated each examination using radiography or computed tomography. However, when imaging the complete spine is necessary, the radiation exposure is significantly elevated. Moreover, collecting a picture in a different location necessitates extra radiation, which leads to an extended examination time [13]. Furthermore, assessing a spinal curve or tilt in a radiograph is traditionally conducted by manually measuring angles, such as the Cobb angle. This method relies on the examiner's expertise and is susceptible to errors resulting from human factors [14]. Magnetic resonance imaging (MRI) offers a non-radiation-based approach for spinal evaluation but at a substantial expense[15]. The three primary non-radiographic techniques used for assessing the spine were rasterstereography, photogrammetry and SM [16].

Two distinct measurement methods primarily characterise raster stereography. The first technique examines the illumination directed into the subject's dermis, which is regarded as a dependable and extensively used way to implement raster stereography [17]. The second approach also demonstrates a comparable degree of dependability, which employs a 3D RGB infrared and time-of-flight camera [18]. Rasterstereography typically provides a diverse array of postural data. Its efficiency characterises it, as it allows for rapid measurements. However, it should be noted that this method is associated with a somewhat costly expense. Photogrammetry, namely in its 2D mode, is widely used as a cost-effective method for conducting kinematic and geometrical analyses of motion and posture. Various software options are available for the execution of this task, and many of them possess credibility and dependability. Photogrammetry is considered a more cost-effective option, although with a lower level of sophistication. The user's proficiency and the software's capabilities influence the level of user-friendliness in photogrammetry. Additionally, photogrammetry lets users get measurements for the whole body rather than only focusing on the spine [19].

Finally, the spinal mouse device (SM) is an external, non-invasive tool used to evaluate the angle and structure of the spine in both the coronal and sagittal planes. The SM, developed by Idiag in Switzerland, is a portable computer-assisted electromechanical instrument that records measures of spinal curvature. SM was measured in the sagittal plane, and the angle relative to the vertical axis was calculated. In addition, the researcher documented the distance travelled by the device's wheels as it traversed the patient's skin. The data were sent to a computer via a serial connection to get a digital representation of the curvature of the skin surface along the human spine. According to the SM Manual, the angular measurement precision was said to be 0.1°, while the distance measurement accuracy was reported to be 1 mm. According to the SM Manual, the data collection process included sampling at intervals of 1.3 mm when the SM device was moved down the spine. This resulted in a sampling frequency of around 150 Hz. The provided data was used to compute the relative orientations of the sacrum and spinal column. The bony spinal column is examined using SM software to analyse its constituent components [20]. The SM measured several variables, including the thoracic kyphosis angle (the sum of 11 segmental angles from Th1/2 to Th11/12), the lumbar lordosis angle (the sum of 6 segmental angles from Th12/L1 to L5/S1), the sacral tilt angle (the angle between a straight line from S1 to S3 and a vertical line), and the spinal tilt angle (the angle between a straight line from Th1 to S1 and a vertical line. The spinal alignment assessment was performed sequentially, with three measurements taken in succession. After that, the average outcome was used for analysis. Also, the SM was used to assess spinal motion. Subjects were instructed to assume a seated position on a chair without a backrest and to flex and extend their spine the maximum extent feasible. The measurements were conducted while the participants were sitting since it is tough for individuals with hip osteoarthritis to keep a bent spinal posture when standing. The pelvis was intentionally left unfixed to prevent interference with natural mobility. The thoracolumbar spine's range of motion (ROM) was determined by adding the angle variations of seventeen segments from Th1/2 to L5/S1. Analysis was conducted utilising the mean value of the three measurements. [21]. In 1994, Dr. Seichert and Prof. Senn from the Ludwig Maximilian University of Munich, Germany, where the Clinic of Physical Medicine and Rehabilitation is located, finished and published a research article that served as the basis for the idea of a device designed to capture the surface of the spine. The SM (Idiag M360) prototype was first developed in partnership with Idiag AG, a Swiss corporation specialising in software development. Idiag AG supported the first distribution of the Idiag M360 devices on the Swiss market in 1999. The impetus for development primarily stemmed from the absence of a methodology or technology capable of non-invasively and radiation-free evaluating the structure and flexibility of the spinal column in a manner that is both easy and expeditious while maintaining reliability and cost-effectiveness [22]. X-rays have long been considered the most reliable way for diagnosing, assessing, and managing spinal scoliosis since other diagnostic techniques are either indirect, costly or not feasible in practical settings. Nevertheless, it is essential to acknowledge that this approach includes the potential hazard of continuous radiation exposure, particularly when repeated exams are required to check the patient's spinal condition, which may result in the development of cancer [23]. This potential harm is one of the drawbacks above.The spine Mouse is reliable and valid in measuring spine alignment and ROM [24].As a result, this research will focus on the non-radiological spinel mouse gadget and demonstrate its effectiveness by comparing it to X-rays using the Cobb angle and other measurement techniques.

This review aims to thoroughly examine spinal deformity, including a detailed analysis of measurement techniques, and explore the underlying clinical factors contributing to its formation. Furthermore, it seeks to evaluate the effectiveness of the non-radiological SM device and assess its reliability in measuring spinal alignment.

**Research methodology**

**Research questions**

This study review primarily aims to examine the architecture and mobility of the spinal column and measure spinal abnormalities utilizing a skin-surface device (SM), a rolling mouse tool for assessing spinal curvatures. Furthermore, the research seeks to determine the precision of SM in relation to other measurement methodologies. The following research topics, which are summarized in Figure 1, were submitted by us in order to accomplish this:

**Q1.** What is the method for quantifying spinal deformity?

**Q2.** What are the variables that influence the morphology of the spinal column?

**Q3.** What non-surgical treatments are used to improve spinal alignment and reduce the effects of age, weight, gender differences, etc.?

**Q4.** Are there any pathological conditions that impact the alignment of the spinal column?

**Selection criteria**

This research aims to provide a thorough categorization of the spine. The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) protocol was utilised in this research to review the current literature systematically [25]. A first inquiry was conducted to discover relevant literature on the spine and evaluate it using an SM device. The research articles were acquired from databases including Springer, Science Direct, Scopus, Web of Science, and several others. The first stage of filtration involves keyword identification, whereas the subsequent stage relies on the titles and abstracts of the articles. A comprehensive examination of the whole text subsequently ascertained the ultimate set of publications. Figure 2 demonstrates that the screening procedure revealed a limited number of relevant articles to our investigation. Figure 3 illustrates the breakdown of publishers, with 18% of journals from Elsevier, 12% from Springer, 7% from MDPI, 4% from PLOS ONE, 2% from Taylors & Francis Publishing, 4% from Hindawi, 5% from Tubitak, 4% from NSP and the remaining 44% from various other publishers. Figure 4 illustrates the distribution of the chosen articles across the years. Table 1 presents the publication of scholarly papers, books, reports, theses, and conference proceedings.

**FIGURE 1.** mapping the questions for research.

**TABLE 1.** Categorization of references.

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Reference type** | **Author** | **Year** | **Reference type** | **Author** | **Year** | **Reference type** | **Author** | **Year** |
| J | [1] | 2018 | J | [28] | 2017 | J | [55] | 2015 |
| J | [2] | 2021 | J | [29] | 2017 | J | [56] | 2016 |
| B | [3] | 2013 | J | [30] | 2018 | J | [57] | 2018 |
| J | [4] | 2021 | J | [31] | 2019 | J | [58] | 2019 |
| J | [5] | 1974 | J | [32] | 2020 | J | [59] | 2022 |
| J | [6] | 2015 | J | [33] | 2021 | J | [60] | 2023 |
| J | [7] | 2011 | J | [34] | 2021 | J | [61] | 2023 |
| J | [8] | 2012 | J | [35] | 2022 | J | [62] | 2023 |
| J | [9] | 2012 | J | [36] | 2022 | C | [63] | 2023 |
| J | [10] | 2005 | J | [37] | 2022 | J | [64] | 2017 |
| J | [11] | 2008 | J | [38] | 2022 | J | [65] | 2017 |
| G | [12] | 2012 | J | [39] | 2023 | J | [66] | 2021 |
| J | [13] | 2004 | J | [40] | 2023 | J | [67] | 2021 |
| J | [14] | 2007 | J | [41] | 2012 | J | [68] | 2021 |
| J | [15] | 2014 | J | [42] | 2016 | J | [69] | 2021 |
| J | [16] | 2023 | J | [43] | 2013 | J | [70] | 2021 |
| J | [17] | 2018 | J | [44] | 2015 | J | [71] | 2022 |
| J | [18] | 2022 | J | [45] | 2016 | J | [72] | 2022 |
| J | [19] | 2023 | J | [46] | 2017 | J | [73] | 2023 |
| J | [20] | 2016 | J | [47] | 2020 | J | [74] | 2023 |
| J | [21] | 2018 | J | [48] | 2020 | J | [75] | 2016 |
| W | [22] | 2018 | J | [49] | 2016 | J | [76] | 2015 |
| J | [23] | 2019 | J | [50] | 2016 | J | [77] | 2017 |
| J | [24] | 2014 | J | [51] | 2017 | J | [78] | 2017 |
| J | [25] | 2023 | J | [52] | 2019 | J | [79] | 2019 |
| J | [26] | 2015 | J | [53] | 2020 | J | [80] | 2021 |
| J | [27] | 2016 | J | [54] | 2020 | J | [81] | 2021 |

B = Book; C = Conference; J = Journal; W= Web; G = Generic.

**Science Direct**

**Springer**

**Scopus**

**Web of Science**

**Others**

**Reading articles that provide exclusive information about the spine and the SM device.**

**82 papers were selected.**

**60** **papers were selected based on their titles.**

**43 papers were selected based on their titles.**

**37 papers were selected based on their titles.**

**31 papers were selected based on their titles.**

**26 papers were selected based on their titles.**

**200 papers were selected after using a filtering process based on the abstract.**

**FIGURE 1.** Illustration of the PRISMA framework for the article's choosing approach.

**FIGURE 3.** Distribution of publisher choices.

**FIGURE 4.** The selected articles are distributed year-wise.

**Study-related motivation**

The suggested review was motivated by spinal deformities in various age groups, which might manifest as alterations in the shape or mobility of the spine. Existing research mainly focuses on investigating the correlation between multiple diseases that impact an individual and their impact on the spine. As a result, complete research is required to address a variety of variables such as age, gender, numerous illnesses, inappropriate sitting or standing posture, and their immediate or long-term effects on the spine.

**Criteria for what is included and excluded**

The parameters for inclusion or exclusion in this assessment are specified in Table 2.

**TABLE 2.** Classification of references.

|  |  |
| --- | --- |
| **Inclusions** | **Exclusions** |
| Specifically relevant to the spine | Characterization of spinal alignment using image analysis and deep learning. |
| The use of the SM device | The Zebris US-based equipment is used for measuring the spine |
| Publication of the article occurred within the last eleven years, from 2012 to 2023. |  |
| Child's age and above | Infant |

**Approaches to the analysis**

Scientists have designed and developed numerous techniques for studying the spine's mobility, function, and curvatures in spinal patients throughout the years. We shall categorize them according to their developmental phases and discuss their advantages and drawbacks. These include goniometers [4], spondylometers [5], scoliometers, kyphometers [6], digital inclinometers [7], flexible curve rullers [7], fingertip-to-floor distance measurements [8], tape measurement methods [4], and the Schober index [9], but more research is needed to determine the reliability and accuracy of metric measurements used to measure lumbar spine mobility and their sensitivity to variation [10]. X-rays and CT scans are precise imaging methods [11]. However, imaging the whole spine increases radiation exposure. Photographing elsewhere requires more radiation, which lengthens the test [13]. A spinal curvature or tilt in a radiograph is often assessed by manually measuring angles like the Cobb angle. This procedure depends on the examiner's skill and is prone to human mistakes [14]. Magnetic resonance imaging (MRI) is a costly, non-radiation spinal evaluation method [15]. The three main non-radiographic spine assessment methods were rasterstereography, photogrammetry, and SM [16]. Two distinct measurement methods primarily characterize raster stereography. Analysing the light projected onto the subject's skin was the first technique used in raster stereography [17]. It is dependable and widely used. Still, this is a costly process. Using a time-of-flight three-dimensional RGB camera with infrared, the second method is reliable [18]. Photogrammetry user-friendliness depends on human skill and program capabilities. Photogrammetry also measures the whole body, not only the spine[19]. Finally, SM measures spine angle and shape in the frontal and sagittal planes externally and non-invasively. The portable computer-assisted electromechanical SM (Idiag, Switzerland) measures spine curvature. In the sagittal plane, SM measured the angle to the vertical [20]. The impetus for development primarily stemmed from the lack of a non-invasive, radiation-free technique or technology that could examine spine shape and segmental mobility quickly, reliably, and cost-effectively [22]. The methods mentioned above are consolidated in Table 3.

**TABLE 3.** Approach analysis.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Approach of analysis** |  | **Advantage** | **Disadvantage** | **Limitation** |
| **A Non-radiography** | Goniometer,Spondylometer, Scoliometer, Kyphometer, Digital inclinometer, Flexible curve ruller, Fingertip-to-floor distance measurement, Tape-measurement, and Schober-index. | Portable and non-invasive. | Difficulty in detecting anatomical signals like the lumbosacral junction and Venus dimples. | Further evidence of the reliability, precision, and sensitivity of metric measures used to evaluate lumbar spine movement. |
| Rasterstereography. | Gives various postural data, and its quick measurements make it efficient. | Costly expense. |  |
| Photogrammetry. | Reliable software  choices are accessible and cheaper but less sophisticated. | Measures the whole body, not just the spine. | Depends on user skill and program. |
| MRI. | Accuracy. | Considerable cost. |  |
| SM. | External, non-invasive, portable, simple to use, faster test. | It had to touch the body while moving on the spinal column skin. |  |
| **Radiography** | X-ray and CT | Increasing accuracy in determining spine flexibility and pre/postoperative conditions. | The biological effects of radiation include cancer and accumulation. Each radiography or CT scan may assess one cervical, thoracic, or lumbar spinal curvature. Radiation increases while imaging the whole spine. Other photography uses more radiation, extending the test. | The Cobb angle is manually measured in radiographs to determine spine curvature or tilt. This method relies on the examiner and is subject to error. |

**SYSTEMATIC STUDIES**

This study comprehensively examines quantitative assessment techniques used on a population-based sample to analyze the correlation between spinal deformity and factors such as age, gender, and other disorders that directly or indirectly impact spinal alignment. The following points provide a chronological account of the most renowned inquiries and investigations by researchers. This evaluation will categorize the studies and research based on the characteristics above and their impact on spine posture and mobility.

**1. Spine functioning in individuals with pathological conditions**

In 2015, Topalidou A. et al. examined spine shape and motion in individuals with fractured vertebrae. The treatment group included forty-three individuals with either percutaneous balloon kyphoplasty or an additional brace. The control group had thirty-nine healthy people. SM was utilized to measure spine curvatures and movement for both groups. Results have been assessed using the visual analogue scale (VAS) and the Oswestry disability index. In the sagittal plane, a statistically important rise in lumbar curve, spinopelvic angulation, and spine tilting occurred at three months. Major frontal plane gains occurred after six months. Patients with osteoporotic fractures had a much lesser average score than traumatic fracture patients. This research offers a full overview of spine functioning in individuals after percutaneous balloon kyphoplasty [26].

A year later, Muramoto A. et al. conducted a follow-up investigation to assess the effects of spinal sagittal alignment on activity levels and locomotor syndrome (LS) among middle-aged and elderly women residing in the community.The research included 125 women aged 40 to 88 years (mean age 66.2 ± 9.7 years). These women underwent evaluations, SM tests, physical examinations, and performance testing as part of the Yakumo study. A 25-question evaluation called the Geriatric-Locomotive-Function-Scale (GLFS-25) and a Visual-Analogue-Scale (VAS) measuring knee stiffness and low back pain (LBP) was given to the participants. A value of more than 16 on the GLFS-25 was used to define LS. The SM was used to measure the angles of spinal inclination (SIA), thoracic kyphosis (TKA), lumbar lordosis (LLA), sacral slope (SSA), as well as the ROM in the thoracic (TSROM) and lumbar (LSROM) regions of the spine. The variables assessed included the maximal gait length, the strength of the back muscles, and the timed-up-and-go test (TUG). The duration of OLS (eyes open, upright on one leg) was also recorded. A study examined the correlation between sagittal features of the spine, GLFS-25, VAS, and physical activity. Twenty-six participants were classified as LS, whereas 99 were not. Following age adjustment, the LS group exhibited higher LBP and knee pain levels, worse physical activity, higher SIA, and lower LLA than the non-LS group. Even considering age variations, there is a significant association between SIA and GLFS-25, TUG, OLS, and maximum stride. The probabilities of falling in LS were 5.0 for the inclined cohort and 4.0 for the non-inclined cohort. The cohort that was prepped showed a rise in GLFS-25 scores and had higher VAS ratings for LBP. The cutoff value for locomotive syndrome, as determined by the SIA, was 6º. Individuals whose SIA was 6º or more were categorised as "Inclined," whereas those with an SIA below 6º were classified as "Non-inclined." Were 21 individuals ordered as "Inclined" and 104 as "Non-inclined". The inclined group had decreased TUG, OLS, and maximum stride metrics compared to the non-inclined group, even when considering variations in age. The results of this study show that LS health and physical activity in middle-aged and older community-dwelling women are impacted by the spine's alignment in the sagittal plane. The SIA is a suitable method for evaluating the risk of developing LS. It is determined by measuring the SIA, and a threshold value of 6º is used to determine the presence of LS [27].

A year later, Çelenay Ş. et al. examined the variation in lower back pain (LBP), sagittal spinal curvature (SSC), and flexibility between women who experience and do not experience urine incontinence (UI). The research comprised a group of 32 females with UI and 41 females without it. SM (IDIAG, Fehraltorf, Switzerland) conducted measurements of sagittal spinal curvature and movement. The LBP, urogenital distress, and disability related to LBP were measured using the Oswestry-Disability-Index (ODI), a visual-analogue scale (VAS), and the Urogenital Distress Inventory 6 (UDI 6). The incontinence group had greater sagittal thoracic, lumbar, and pelvic curvature than the control group (P < 0.05). The incontinence group significantly improved both sagittal lumbar and pelvic mobility (P < 0.05). The prevalence of LBP was 71.9% among women with UI, whereas those without UI had a prevalence of 12.2%. The VAS demonstrated a correlation coefficient (r) of 0.363 and a significance level (P) of 0.041, while the ODI revealed a correlation coefficient of 0.511 and a significance level of 0.003. Both the VAS and ODI exhibited correlations with the UDI 6. The UI requires careful attention to sagittal-spinal-alignment and excessive motion of the lumbopelvic region [28].

In parallel, Kaya D. et al. looked at pain correlation, cutoff points, and the curvature and mobility of the thoracic spine in individuals with and without chronic neck pain (CNP). The study included 56 patients with CNP and 53 healthy persons. The participants used SM equipment (Idiag, Fehraltorf, Switzerland) to measure the sagittal thoracic curvature and mobility, and they used a Visual Analogue Scale (VAS) to rate the level of their neck discomfort. The CNP group showed a considerable decrease in mobility (P = 0.013) and the thoracic curvature significantly increased (P < 0.001) in comparison to the control group. A negative association with movement (r = -0.260, P = 0.006) and a positive correlation with thoracic curvature (r = 0.391, P < 0.001) were seen in the intensity of discomfort. The threshold values for thoracic curvature and movement were set at 45.5° and 30.0°, respectively, to determine the presence of neck pain. A thoracic curvature of 45° or greater and a reduction in mobility surpassing 30° may be necessary for individuals with CNP [29].

In Aprato A. et al. conducted a study to evaluate the degree of lumbar hyperlordosis and ROM in patients with femoroacetabular impingement (FAI) who had arthroscopic treatment with that of healthy volunteers in 2018. The research included 17 people in good health (control group) and 21 who had undergone surgical treatment for FAIG. An analysis was conducted to examine the diversity of age and gender within groupings. In addition to a spinal shape examination utilising SM, both participants were subjected to a flexibility evaluation, including the Sit and Reach test. The data was analysed using statistical techniques such as descriptive and one way ANOVA. The groups exhibited no significant differences in age, gender, and BMI (p > 0.05The FAIG group decreased their lumbar range of motion significantly (20.70 (SD 9.06) versus 27.77 (SD 9.95; p = 0.021)), increased their lumbar rigidity especially (63.20 (SD 14.50) versus 72.62 (SD 11.87; p = 0.040)), and decreased their Sit-and-Reach test scores significantly (26.02 (SD 9.76) versus 33.48 (SD 9.81; p:). Every p-value in the two sets was more than 0.05, indicating no discernible differences. Individuals with FAI have decreased flexibility in the lumbosacral region, but do not show higher angles of hyperlordosis. These results suggest that including spine mobility courses in post-arthroscopy therapy might be beneficial [30].

In the same year, The radiographic indicators for hip osteoarthritis (OA) over 12 months were identified by Tateuchi H. et al. These indicators comprised functional hip limitations, spinal alignment, and mobility. Fifty female participants with secondary hip OA—apart from those that had severe hip OA—were included in the prospective group trial. The width of the hip joint space (JSW) was measured at the first time point and again after 12 months. The research used the technique of logistic regression to ascertain the factors that might predict the development of hip OA in persons with functional impairments in the hip and spine. The investigations were carried out with and without baseline JSW, BMI, and age controls. The focal point of concern was the advancement of hip OA as seen by radiographic progression over 12 months, specifically any increase more significant than 0.5 mm in JSW. The independent variables assessed in the study were hip discomfort, measured using a visual analogue scale and the Harris hip score (HHS). The HHS, hip morphological characteristics, hip passive ROM, and muscular strength were examined using a conventional goniometer and a portable dynamometer. The SM, manufactured by Index Ltd. in Tokyo, Japan, was used to evaluate the alignment and mobility of the thoracolumbar spine in the first stage. Out of the total number of participants, specifically twenty-one, which accounts for 42.0% of the individuals, had radiological development of hip OA. The development of hip OA is strongly correlated with an increase in anterior spine tilt while standing up (adjusted OR [95% CI], 1.37 [1.04 to 1.80]; P = 0.028), according to a logistic regression analysis with multiple variables. Furthermore, it was shown that the development of hip OA was substantially correlated with an initial reduction in thoracolumbar spine movement (adjusted OR [95% CI], 0.96 [0.92 to 0.99]; P = 0.037). The research proposes that while assessing the risks and adopting preventive measures for the advancement of secondary hip OA, it is essential to consider the spine's alignment and mobility [21].

In 2019, Candan S. et al. examined the impact of upper trunk brachial plexus palsy (OBPP) on spine curvature and the correlation between the degree of curvature and upper extremity motions. The sagittal and frontal arc of the spine was measured using SM. One research cohort measured upper limb motions using the active movement scale. Frontal plane curves were more significant in the research cohort. 11 of 25 (44%) kids in the OBPP cohort developed thoracal C-shaped scoliosis. Nine kids had contralateral scoliosis. Shoulder outside rotation was negatively linked with scoliosis angle. In the OBPP category, scoliosis kids had decreased shoulder external rotation and elbow flexion. OBPP in the upper trunk may alter the frontal plane alignment. Inadequate shoulder external rotation values might cause thoracal scoliosis due to trunk compensation [31].

After a year, Machino M. et al. discovered the potential risks associated with locomotive syndrome (LS) in middle-aged and elderly adults during a health check. Low back pain (LBP), spinal degeneration, decreased muscular strength and diminished athletic capacity are some of these risks. This research assessed a cohort of 211 Japanese persons (89 males and 122 females) with no health issues. The average age of the participants was 64.0 years. Radiography and SM were used in the evaluation process. The spinal sagittal parameters used for measuring spinal sagittal variables were the thoracic kyphosis angle (TKA), lumbar lordosis angle (LLA), sagittal vertical axis, and spinal inclination angle (SIA). The examination of spinal degeneration at each level included assessing lumbar disc height (LDH) and the formation of lumbar osteophytes (LOF). The LS test consisted of evaluations including the ability to stand up, do a two-step movement, and complete the 25-question Geriatric-Locomotive-Function-Scale (GLFS-25). Using the LS hazard assessment criteria, the subjects were divided into three groups: no risk, stage 1 LS, or stage 2 LS. The prevalence of LBP was assessed using a Visual-Analog-Scale (VAS), and athletic capacities were compared across various groups. Among the whole population, 122 individuals were not exposed to any LS threat, 56 individuals experienced stage 1 bet, and 29 individuals encountered set 2 danger. The prevalence of LBP and the level of discomfort, as assessed by the VAS, escalate with the severity of the LS hazard stage. Nevertheless, there is a decline in both posterior muscle strength and athletic prowess. The value of TKA was consistent across all three cohorts. According to P = 0:0001, the LLA steadily declined as the LS threat level rose. The LDH levels consistently reduced with the presence of LS danger at all levels, save for L1-L2 and L5-S1. The frequency of LOF events increased dramatically in correlation with the danger stage of the LS. The SIA exhibited a notable rise in association with the LS hazard stage, demonstrating a statistically significant p-value of 0.0167. Individuals with LS showed increased occurrences of spinal degeneration, decreased LLA, and overall spinal imbalance resulting from anterior spinal inclination [32].

After a year, Ozer Kaya D. et al. conducted a study to analyse the characteristics and restrictions of women with double crush disease. They compared these women's spinal alignment to healthy women's and identified disruptions in spinal alignment. Twenty women, averaging 49.50 ± 8.64 years old with double crush syndrome, and twenty-one healthy individuals, averaging 44.76 ± 7.82 years old without symptoms, made up the study. An analysis was conducted on the physical characteristics, level of discomfort, and symptoms. The Neck Disability Index, SM VR (Idiag, Fehraltorf, Switzerland) for assessing spinal alignment, and the Disability of Arm and Shoulder Questionnaires were among the evaluation tools used. The pain level ranged from 3.70 ± 3.25 cm during rest, 6.01 ± 2.77 cm at bedtime, to 7.15 ± 2.68 cm during activity. The most severe manifestation was numbness, affecting 65% of individuals. Hands and digits exhibited the symptoms at 55%, followed by arms at 15%, shoulder blades at 15%, and the neck at 15%. The Disability of Arm and Shoulder Questionnaire yielded results of 58.64 ± 15.41, whereas the Neck Disability Index yielded results of 19.55 ± 6.37. Individuals with double crush syndrome saw a notable increase (p:.011) in the sagittal thoracic and lumbar curvatures, but the overall mobility of the spine significantly decreased (p<.001). The threshold values for thoracic spinal curvature were 54.5º (with an area under the curve of 0.680, p-value of 0.049, sensitivity of 40%, and specificity of 99.9%). The complete spine mobility threshold was 113.5º (with a region beneath the curve of 0.667, p-value < 0.000, sensitivity of 65%, and specificity of 99.9%). Patients diagnosed with double crush syndrome exhibit significant discomfort ranging from moderate to severe, along with a notable decline in thoracic and lumbar curvature and restricted mobility of the spine. The established thresholds for thoracic curvature were 54.5º, whereas the ROM for the spine was measured at 113.5º [33].

During the identical year, ERDOĞAN A. et al. analysed the correlation between thoracic kyphosis angle, dyspnea perception, and chronic obstructive pulmonary disease (COPD) patients' health state, revealing the postural impact. In the research, 105 COPD individuals (68.10±8.59 years, FEV1:47.59±21.50%) participated. The SM gadget quantified the angle of thoracic kyphosis, while the Modified Medical Research Council (MMRC) Dyspnea Scale assessed the level of dyspnea. Health specific to the illness was evaluated using the COPD assessment test (CAT) and the Clinical COPD Questionnaire (CCQ). The participants were divided into three categories by thoracic kyphosis angle: 20°-50°, 51°-60°, and 61°-90° and compared. A minimal positive correlation was found between thoracic kyphosis angle and dyspnea perception (rho=0.23, p=0.02), but not with disease-specific health status (rho<0.20, p>0.05). Identical CAT and CCQ scores were found between groups (p>0.05). Group 3 had increased dyspnea awareness (p=0.03) with thoracic kyphosis angle>60°. Increasing thoracic kyphosis angle in COPD patients leads to increased dyspnea perception, whereas disease-specific health status stays unchanged. COPD patients' postures require being carefully assessed during physiotherapy and rehabilitation to address thoracic kyphosis-related dyspnea. Additionally, initial preventative measures like exercise and ergonomics should be performed for thoracic kyphosis [34].

In 2022, Sarvari S. et al. assessed upper extremity anomalies through COVID-19 isolation. It highlights the impact of physical exercise and screen time on abnormalities in male teenagers. The link between these components and anxiousness was also explored. This descriptive-correlational research included 150 (13-15-years) males. Evaluate upper extremity anomalies via Image J and SM. Physical activity, screen time, and anxiousness are measured using conventional questionnaires. Mean age and BMI were 22.86 and 22.48. The study found that 47% of patients had forward head position, 34% had kyphosis, and 7% had lordosis. Significant correlations were found between physical activity, screen time, forward head and kyphosis (all T>1.96). Significant associations were seen between anxiety and physical activity, screen time, and upper extremity anomalies (all T>1.96). Results reveal widespread upper extremity anomalies, such as forward head and kyphosis, in male adolescents during COVID-19 isolation. Screen usage and physical exercise may also contribute to these problems [35].

In the same year, Taniguchi M. et al. undertook an experiment to investigate the links between osteoarthritis (OA) knee symptoms, functional limitations, low back pain (LBP), and lumbar kyphosis.A total of 586 individuals with radiographic-confirmed knee OA were included in the research, with 80.1% being female and the mean age being 68.8 ± 5.2 years. The participants were 60 or older and were part of the Nagahama Project. The evaluation of functional limitations and knee-related issues was conducted using the Knee Society Knee Scoring System (KSS). LBP is defined as chronic back pain that lasts for more than three months. Lumbar kyphosis was evaluated using the SM, a computer-assisted electronic tool that uses skin-surface techniques. A multiple linear regression analysis investigated the relationship between LBP, lumbar kyphosis, and KSS scores. Analysed were gender subgroup data. After accounting for related factors, both LBP and lumbar kyphosis were shown to be independently associated with lower KSS function scores. When either low back pain (LBP) or lumbar kyphosis (LK) was present alone, the mean score difference was -4.96 (95% CI -7.56, -2.36); when both symptoms were present at the same time, the mean score difference was -13.86 (95% CI -18.86, -8.86). Patients rated their KSS symptoms lower after lumbar spine kyphosis and low back pain were treated together (mean difference -4.49 [95% CI -6.42, -2.55] points). The results indicate that individuals with knee osteoarthritis who have low back pain and lumbar kyphosis may face restrictions in their physical abilities and experience discomfort in their knees [36].

Also the same year, ZILELI A. et al. have identified differences in muscular activation, posture, and vertebral mobility across healthy persons and lumbar spinal stenosis sufferers. The research compared 48 participants with lumbar spinal stenosis (LSS) (a mean age of 55.19 ± 10.41 years) against 48 healthy persons (a mean age of 58.15 ± 8.44 years). Subjects were assessed using an SM for posture and spinal mobility in upright and maximal flexion. A surface electromyography device (sEMG) was used to evaluate muscular activation in the gastrocnemius muscle through maximal voluntary contraction and walking. The two categories had equal maximum trunk flexion, upright segmental posture, and mobility (p > 0.05). There was an essential distinction in overall mobility scores (p < 0.05) and muscular activation measures (p < 0.05) between the two categories. A comparison of LSS and healthy individuals revealed comparable segmental posture and spinal mobility but reduced muscle activity and total vertebral movement in the LSS cohort [37].

Within the same year, Roghani T. et al. investigated the association between thoracic kyphosis, back extensor strength (BES), and back extensor endurance (BEE). They tested the range of motion (ROM) of the spine in elderly women who had or did not have hyperkyphosis. The assessment of sagittal spinal curvature and ROM was conducted using the SM. Furthermore, the evaluation of BES and BEE was carried out using a load cell. The study used an independent sample t-test to compare older women with and without hyperkyphosis. The Pearson correlation coefficient was used to establish the relationships between parameters. Multiple linear regression was utilized to determine the best kyphosis-associated parameters. The hyperkyphosis category had considerably less ROM in the lumbar and thoracic regions of the spine than the conventional category (P<0.05). There was a correlation between thoracic kyphosis and total lumbar ROM (r=-0.30, P=0.03), entire spinal ROM (r=-0.35, P=0.01), BES (r=-0.73, P<0.001), and BEE (r=-0.60, P<0.001). After controlling for age, weight, and BMI, the multiple linear regression analysis found a significant association between BES (P<0.001) and BEE (P=0.01) with thoracic kyphosis. However, spinal ROM (P=0.16) did not indicate a significant association. When contrasted with women who had normal kyphosis, those with hyperkyphosis showed less ROM in their spines. Total lumbar and spinal ROM, BES, and BEE were all associated with thoracic kyphosis. However, multivariate regression showed that ROM was not a significant factor in the disease. When treating hyperkyphosis, it is essential to address BES and BEE because of their substantial contributions to thoracic kyphosis [38].

After a year, Piancino M. et al. examined if unilateral posterior crossbite (UPC) with functional shift affects reverse chewing and spine flexion. A Kinesiograph (Myotronics-Noromed Inc., USA) captured individuals who had UPC and a control category with normal obstruction chewing both hard and soft boluses. A computerized inclinometer SM measured spine posture. Out of 87 children who had UPC, 38 (median (IQR) age 8.0 (7.3–9.3) years) were measured prior to and following therapy. A larger proportion of UPC individuals had anomalous/reverse chewing habits on the crossbite side compared to thecontrol group (p < 0.001). In the patient category, both sides of the spine flexion angles differed significantly (p < 0.001 and p = 0.001, paired t-test), with the crossbite side being more flexible than the non-crossbite side. Neither the control category nor post-treatment for both sides of the crossbite showed similar variations (p = 0.44 and 0.15, paired t-test). This research links UPC, asymmetrical chewing, and spine flexion. These findings may benefit diagnosis and therapy by revealing a link between oral malocclusions and spine posture [39].

Also that year, Celenay S. assessed postural stability, spinal alignment, mobility, and competence in women with unilateral lower extremity lymphedema after gynecologic cancer radical hysterectomy compared to a matching control cohort. The study comprised 27 females with unilateral lower extremity lymphedema (54.14 ± 5.80 years) and 30 healthy females (51.90 ± 6.54 years). Lymphedema intensity was assessed using circumferential measures. Assessments included stable posture using the Biodex Balance System SD and spinal alignment, mobility, and competence using the SM gadget. The study indicated that 3.7% of females had mild lymphedema, 7.4% had intermediate, and 88.9% had extreme lymphedema. The lymphedema cohort demonstrated significantly better stability than the control group in holding static postures with their eyes open (EO) and eyes closed (EC) in terms of mediolateral, anteroposterior, and total stability (p < 0.05). Lower spinal mobility and posture competence ratings were seen in the lymphedema cohort compared to the control cohort (p < 0.05). Additional variables were similar across groups (p > 0.05). Reduced postural stability, mobility, and competence have been viewed in females with unilateral lower extremity lymphedema, but no variation in spinal alignment was observed. Adjustments should be considered while assessing and treating unilateral lower extremity lymphedema [40].

**2. Spine functioning in individuals with non-pathological conditions**

**2.1 Spine functioning in a pregnancy and the menstrual cycle**

In 2012, Okanishi A. et al. investigated postural alterations in pregnant and non-pregnant women. Fifteen women at 17–34 weeks of pregnancy were studied, whereas ten non-pregnant women were in the control category. Standing posture was assessed sagittally using static digital images. Image analysis software assessed trunk-pelvis and trunk-lower extremity angles. SM was used to detect and quantify sacral, thoracic, and lumbar curvature and tilt. The main elements were computed till independent values exceeded 1. Three components with independent values of 1.00-2.49 were discovered, indicating lumbosacral, thoracic, and body tilt. Such variables explained 77.2% of posture variation. In 11 pregnant women, postural features included lumbar kyphosis and sacral posterior tilt. In comparison with healthy women, body tilt varied. Spinal curvature predicted lumbar kyphosis in pregnant women. Pregnancy can alter spinal curvature and posture, leading to discomfort. These data offer a foundation for studying how spinal curvature and postural alterations impact pregnant symptoms [41].

After a gap of four years, Kaya D. et al. compared  anxiousness state, spinal posture, mobility, positional competence, and stabilization in active females throughout their menstruation cycles. Thirteen active 18–25-year-old females with regular menstruation cycles were selected. The Spielberger State-Trait Anxiety Inventory, SM device (Idiag, Fehraltorf, Switzerland), and Biodex Balance System SD (Biodex Medical Systems, Inc., Shirley, NY, USA) were employed to assess anxiousness, spinal posture, mobility, and competence throughout menstruation. No significant variations in apprehension, spinal posture, mobility, or competence were seen during cycles of menstruation stages (P > 0.05). Dynamic postural stability differed significantly among the three stages of the menstruation cycles (P < 0.05), whereas static postural stability did not alter (P > 0.05). Overall stability, anterior-posterior, and mediolateral scores were most excellent during menstruation and lowest during the mid-luteal phase. The menstrual cycles did not affect state anxiety, spinal posture, mobility, or postural competence. Menstruation causes a decrease in dynamic stability. Understanding how menstruation affects the capacity to maintain balance and stability during physical activity might help reduce accidents among active women [42].

**2.2 Spine functioning in school children's**

In 2013, Elizabeta P. et al. discovered schoolchildren's incorrect posture using clinical exams and aSM. Eight hundred forty adolescents aged 6-15 in nine fundamental educational groups were examined using spine mouse device software and four routine clinical tests. The examination result was most clear in the 2nd grade, and 75 per cent of the population was clear in test one. The proportion of students with positive results was significant, although class frequency was not (p>0.05). While school exam results are qualitative and not utilized for condition assessment, the spine mouse device effectively detects poor posture in youngsters [43].

Following two years, Imhof K. et al. investigated elementary school children's back discomfort, spinal mobility, alignment, and fitness. The current cross-sectional research evaluated 395 Basel-Stadt first-graders (age 7.3 y (SD 0.4)). The waist size, BMI, and body fat measurements were taken using standard paediatric procedures. Among the exercises used to determine physical fitness were a 20-meter shuttle run, side hops, sprints, and reverse beam balancing. For pelvic tilt, thoracic spine, lumbar spine, and spinal inclination, the SM MediMouse® examined spinal mobility and posture. Proxy-reported back pain questionnaires were used. Children with higher spinal mobility outperformed those with lower flexibility in jumping sideways, 20 m sprints, and balancing backwards (p<0.001, d=0.7; p<0.001, d=0.8). Boys with poor posture (pelvic tilt: p=0.01, d=0.6; spinal inclination: p=0.04, d=0.5) performed worse in 20 m shuttle running than those with normal posture. There was no correlation between physical fitness, spinal flexibility, posture, and back discomfort (p>0.1). High physical fitness correlates with increased pelvic tilt and spinal inclination in early children. Poorly aerobic boys had postural insufficiency [44].

**2.3** **Studies to evaluate the precision of the SM gadget**

In 2014, Topalidou A. et al. assessed the testing and retesting accuracy of the SM, a new, noninvasive, computer assisted wireless telemetry device used for measuring the curvature, movement, and functioning of the spine. Fifty individuals who had either back or LBP were used to evaluate the reliability of the testing and retesting. Twenty-four parameters related to the functioning of the spine and position were recorded and calculated for each plane. Measurements in the sagittal plane include the hip sacral angle, trunk tilt angle, lumbar curvature (L1-L5), and thoracic curvature (T1-T12). Thoracic curvature (lateral curvature) (T1-T12), lumbar curvature (lateral curvature) (L1-L5), hip-sacral angle, and angle of trunk tilt are all frontal plane measurements. The accuracy was assessed using the intraclass correlation coefficient (ICC) and the standard error of measurement. Within the sagittal plane, 22 of the 24-parameters demonstrated good and satisfactory dependability, whereas only two exhibited fair and inadequate reliability. Seventeen parameters showed high and acceptable dependability in the frontal plane, whereas five parameters exhibited acceptable reliability, and two values showed poor reliability. The SM showed excellent reliability between tests when evaluating the sagittal plane movement, deformity, and spine curvature. However, its performance was significantly less satisfactory in the frontal plane [15].

Two years later, Zafereo J. et al. examined the accuracy of employing a skin-surface instrument to evaluate global and segmental thoracic and lumbar spine motion in volunteers who had or did not have low back pain (LBP) and to compare the two categories. Forty volunteers participated in the study: twenty adults with LBP and twenty adults of the same age and gender without LBP. Two unassisted raters documented the thoracic and lumbar spine movement, namely from the seventh cervical vertebra to the third sacral vertebra, on the same day. The volunteers were positioned at the maximum extent of their upright bending and stretching. Researchers found a good agreement between raters (ICC = 0.82-0.98) and between raters regarding the thoracic and lumbar bending and stretching mobility in LBP participants. The LBP volunteers measured the lumbar spine flexion in segments, and there was moderate to high agreement amongst raters (ICC = 0.77-0.93). Volunteers with and without LBP did not exhibit any notable disparities in the total ROM while bending or stretching the thoracic and lumbar spine. When measuring entire ROM in the lumbar and thoracic areas, individuals with LBP exhibit acceptable repeatability when using a device applied to the skin's surface. Individuals with LBP had only modest accuracy in segmental end-range mobility during lumbar bending [45].

In 2017, Roghani T. et al. tested the accuracy of a skin-surface device (SM), Idiag, Voletswil, Switzerland) in evaluating upright sagittal tilt and spine flexibility in senior women with and without hyperkyphosis. Data were taken from Nineteen women with hyperkyphosis (thoracic kyphosis angle ≥50°), average age 67 ± 5 years and Fourteen women without hyperkyphosis (thoracic kyphosis angle <50°), average age 63 ± 6 years. The SM measured sagittal, thoracic, and lumbar spine deformation and flexibility at static standing, complete spinal flexion, and extension. Two days apart, the identical tester conducted exams with a 72-hour delay. To assess intrarater accuracy, ICC, typical deviation of evaluation, and lowest observable variation were examined. ICC was 0.89–0.99 in the two categories. The hyperkyphosis category had typical deviations of assessment between 1.02°– 2.06° and the normal category between 1.15° – 2.22°. The hyperkyphosis category had a limited observable shift of 2.85° to 5.73° and the normal category up 3.20° to 6.17°. The SM has high intrarater accuracy for measuring sagittal, thoracic, and lumbar spine deformation and flexibility in senior women [46].

Following a span of three years, Demir E. et al. tested the SM gadget for accuracy in measuring frontal and sagittal measurements in asymptomatic female adolescents. In this study, twenty-eight female students aged 15-18 (16.29 ± 1.08) from high schools in Antalya were studied. Both frontal and sagittal planes were measured with the SM gadget one week apart. The ICC assessed the accuracy of the two measurements. In that research, the thoracic and lumbar region measurements in the frontal plane displayed acceptable accuracy (ICC: 0.591-0.665) and in the sagittal plane, high precision (ICC: 0.867-0.876). In the current research, frontal plane thoracic and lumbar region test-retest results were mildly accurate. Thoracic and lumber curves in the sagittal plane illustrated high accuracy between tests. Evidence suggests that the SM gadget is a convenient and precise tool for physiotherapists to diagnose and evaluate spine issues, provided proper application principles are followed [47].

For the same year, Ruthard K. et al. investigated the intra-rater validity of SM assessments for youngsters with cerebral palsy (CP) and changes following one week of therapy. The examination included 168 SM investigations done on 28 children with CP. The studies were completed in both the sagittal and frontal planes. Of the 28 children, 10 were female, and their average age was 9.7 ± 3.1 years. The measurements were taken at three different time points. The validity of the measurements was verified using two consecutive measurements (t1, t2) taken one day apart. The first and final assessments (spanning five days) evaluated individual modifications after the treatment (t3). The sagittal and frontal planes showed satisfactory intra-rater validity for SM measurements, with ICC values ranging from 0.69 to 0.99. There were substantial improvements in spinal inclination (t1: 12.82 ± 5.40, t3: 11.11 ± 5.60, p = 0.014, Cohen's d = 0.43) and spine length (t3: 409.25 ± 63.58, p = 0.030, Cohen's d = 0) after one week of rehabilitation therapy for children with CP. This demonstrates that SM is capable of adequately assessing spinal function in children with special needs (CP). Furthermore, therapeutic interventions may result in significant posture changes, notably in spinal inclination (Inc) and length (SL) [48].

**2.4 Studies to compare SM performance with other measuring techniques**

Research on the reliability and accuracy of SM measurements and Cobb angles in individuals diagnosed with adolescent idiopathic scoliosis (AIS) was carried out in 2016 by Livanelioglu A. et al. In the research, 51 cautiously monitored AIS individuals were chosen. The individuals receiving treatment had an average age of 14.4 years (9-18 years). Two physiotherapists used SM to analyze frontal plane arcs and then contrasted the findings with radiological data. Two orthopaedic specialists conducted radiological measurements. There was no significant distinction between Cobb measures and SM data of observers one and two (p = 0.505). The Cobb and SM measures showed high interobserver and intraobserver reliability (ICC = 0.872-0.962). Interobserver SM variances were smaller than interobserver Cobb angle variances (p = 0.003) when comparing ratings. Curves with an angle greater than 40° exhibited greater accuracy in measuring Cobb and SM values. Data collected using Cobb and SM methods showed a strong connection (p < 0.0001). SM is a secure, trusted, rapid, and simple approach for clinic investigation and patient monitoring with no adverse reactions. However, it should not be the only determinant in selecting a therapy strategy for AIS individuals [49].

A study conducted by Yi Y. et al. in the same year compared the Back Mapper to the SM—a rolling mouse device used to measure spine curvatures—and the Cobb angle—a measurement determined by X-ray—to determine the instrument's validity and reliability. The exam was administered to twenty healthy young people in order to assess simultaneous, intra, and interrater validity. Scoliosis assessment tools, including Cobb's angle, SM, and Back Mapper, were employed in the exams. Accuracy and validity were evaluated using the ICC and the observation standard deviation. With the exception of calculating the lordotic angle, the Back Mapper showed good intrarater reliability (Cronbach's α=0.821-0.984, ICC=0.696-0.969). Assessing trunk imbalance, scapula rotation, thoracic angle, lumbar angle, and kyphotic angle revealed high interrater reliability (Cronbach's α=0.870-0.958, ICC=0.770-0.919). While Cobb's angle from an X-ray was linked to trunk tilt (r=0.532, p<0.05), the kyphotic angle of the SM showed a significant correlation with the Back Mapper (r=0.510, p<0.05). In healthy individuals, the Back Mapper shows good intra-reliability; however, inter-reliability requires more training. Compared to the Back Mapper settings, the Cobb angle utilizing X-ray seems to be more appropriate [50].

After one year, Cohen L. et al. assessd the dependability and accuracy of non-radiographic approaches for determining global sagittal balance. After searching five electronic data stores, a pair of outside observers examined the system via the 13-item Brink and Louw critical evaluation instrument for reliability and validity. A total of 14 publications discussing six different approaches were discovered among the 3940 entries. The six nonradiographic approaches were SM, infrared motion analysis, photogrammetry, surface topography, and ultrasound. To assess the accuracy of the construction, we used surface topography measurements with R values of 0.49 and 0.68, both with a significance level of p < 0.001. Additionally, infrared motion analysis with an ICC value of 0.81 and plumbline testing with an ICC value of 0.83 were utilized. The surface topography was highly reliable (Cronbach α = 0.985), whereas the SM had moderate reliability (ICC = 0.67). By way of infrared motion analysis, the acceptability range extended from 0.9 mm (as determined by a plumbline) to 22.94 mm. There were challenges in meta-analysis because of the diversity of research participants, component collecting, and statistical analysis. A total of fourteen investigations were conducted to investigate the validity and accuracy of non-radiographic techniques for global sagittal balance. A lack of information suggests non-radiographic approaches have moderate to good dependability, with only three research techniques showing moderate to excellent accuracy. Quality and methodology varied widely across the articles involved. Future studies should investigate the accuracy of non-radiographic approaches by presenting clinically meaningful indicators of acceptance [51].

Increased functional residual capacity's implications on finger-floor distance and sagittal curves of the spine in healthy teenage individuals were investigated by Takeuchi Y. et al. in 2019 using the SM. The study comprised a cohort of 39 healthy individuals with an average age of 21.2 ± 0.8 years. The measurement of trunk flexion included assessing the distance between the fingers and the floor during exhalation at rest, as well as at two different levels of functional residual capacity: 1,000 and 2,000 ml of air exhaled during relaxation. During finger-floor distance measurements, the shape of spinal curvature was assessed utilizing the SM in the sagittal plane upon flexion under increasing functional residual capacity and resting exhalation levels. To evaluate functional residual capacity, finger-floor distance and the curves of the spine were analyzed utilizing one-sided multiple measurement analysis of variance and posthoc analysis. There were significant impacts and variations in finger-floor length across all situations—no substantial effect on spinal curvature. Trunk flexion may be decreased by raising available residual capacity. People who suffer from chronic obstructive pulmonary disease (COPD) may also exhibit this correlation [52].

After a year, the non-radiologic SM method to the Cobb angle and the radiologic Harrison Posterior Tangent Method (HPTM) for lumbar lordosis determination were assessed by Russell B. et al. Using an SM, sixteen patients with lateral lumbopelvic radiographs underwent non-radiographic lordosis testing. Two researchers examined each radiograph using the HPTM and Cobb angle measurement. The Spearman rank correlation coefficient was used to investigate the associations between HPTM, the Cobb angle, and SM. The ICC was used to assess the level of agreement amongst examiners for both the HPTM and the Cobb angle. The HPTM demonstrated a strong association with the Cobb angle, with a Spearman correlation coefficient of 0.936 and a significance level of P < 0.001. When compared to the HPTM (r=0.707, P=.003) and Cobb angle (r=0.337, P=.002), the SM technique demonstrated moderate to substantial relationships. With all ICC values > 0.90, the Cobb angle and HPTM show outstanding dependability among and between examiners. HPTM and SM identified a slight curvature of the spine in one person. However, the Cobb angle measurement, explicitly assessing the L1 and L5 vertebrae, suggested a substantial inward curvature. HPTM measures correlated well with the Cobb angle but took additional time and effort, and normal ranges were not yet determined. While radiographs may not be suitable, the SM may evaluate soft tissue shapes instead of lordosis [53].

Concurrently, that year, Jung S. et al. examined the relationship between the SM (continuous measurement), Flexicurve, and Arcometer (selective measurement). To assess thoracic kyphosis, 89 healthy adults were evaluated using non-radiological methods (SM, Flexicurve, and Arcometer). There was a strong correlation between the SM and Flexicurve measurements of thoracic kyphosis (ICC=0.53, 95% CI=0.37–0.67). High agreement (ICC=0.58, 95% CI=0.42–0.70) was found between SM and Arcometer assessments of thoracic kyphosis. The average variance between the SM and the Arcometer was 12.70 degrees, whereas the conflict between the SM and Flexicurve was 23.83 degrees. Although Flexicurve and Arcometer are substantially linked with SM, they have low accuracy. Thus, rehabilitation professionals should interpret its findings with care [54].

Three years later, Belli G. et al. determined the most appropriate linear regression model which could connect SM analytic kyphosis data to one or more photogrammetry (PG) body posture indicators in adolescents with kyphotic posture. Thirty-four teenagers diagnosed with structural and non-structural kyphosis underwent analysis utilizing (SM) and (PG) techniques. This analysis was conducted in both an upright posture and throughout forward flexing, enabling the measurement of many parameters, including body vertical inclination, trunk flexion, sacral inclination, and hip position. The most influential factors were the hip location in the PG and the angle formed between the horizontal line and the sacral endplate-C7 spinous process. The adjusted-R2 values for SM bend and SM fixed bending were 0.804 and 0.488, respectively, with p-values less than 0.001. Many SM and photogrammetry indicators correlated when teenagers were forward bending, particularly when measured. Physicians and kinesiologists may find photogrammetry useful for predicting spinal curves [19].

**2.5 The impact of posture, age, gender, and smartphones on spinal alignment**

In 2015, Yoon J. et al. examined how smartphone usage affects the lumbar spine, redirecting inaccuracy and curvature during treadmill walking. Twenty healthy adults (18 men and two women) participated in the research. Treadmills users walked for 20 minutes while using a smartphone. Lumbar redirecting errors were recorded via an electronic goniometer to study the impact of smartphone usage, and lumbar curvature was determined with an SM before and after treadmill usage. The paired t-test compared before and after-walking lumbar redirecting error and curvature information. The lumbar spine relocation error was substantially higher after walking (6.70±2.91° vs. 3.02±1.79°). There was no significant change in lumbar curvature before and after walking (14.24±3.18° vs. 13.94±3.12°). Smartphone use increased lumbar relocation inaccuracy quickly following strolling, whereas lumbar curvature remained stable [55].

One year later, Mihcin S. studied spinal unstableness, a technique was created utilizing the Thrustline hypothesis. First, a prototype postural dataset pool of 40 healthy men and women was created utilizing a SM to capture the respective postures of vertebral bodies for the mathematical design. After that, an internal code determined the vertebral bodies' 2D coordinates. According to Student's t-tests, posture differences were more significant in X coordinates (p-value <0.01) and Y coordinates (p-value <0.05). A pilot database is needed to measure spinal stability for both sexes due to postural variances. Flow graphic showed application viability. It is suggested to combine the program with electromyography (EMG) for clinical use [20].

At the same time, Masaki M. et al. evaluated the relationship between 35 middle-aged and older women's rate of walking, age, sagittal-spinal-alignment, muscular thickness, and lumbar muscle quality. A sagittal-spinal-alignment assessment was conducted using an SM. This assessment included lumbar lordosis, thoracic kyphosis, and sacral anterior tilt angle. Using ultrasonography, the thickness and echo intensity of the erector spinae, psoas major, and lumbar multifidus muscles were measured. The average walking pace was shown to be utterly dependent on age, according to the findings of the stepwise regression analysis. The lumbar erector spinal muscle thickness has a notable independent impact on the maximal pace of walking. Instead of keeping their spines in an upright position, slower-walking middle-aged and older women tend to have lesser lumbar erector spinal muscles [56].

In 2018, Walaa S. et al. studied scoliosis occurrence and related torising years of study among physical therapy students at Majmaah University, Saudi Arabia. One hundred fifty-two physical therapy students aged 20-24 were studied. The pupils were 92% female and 60% male. An SM assessed the student's frontal plane spine deformation. Scoliosis was prevalent among physical therapy students at Majmaah University (31.5%), especially among females, with a 3:1 female-male ratio. The occurrence of female student scoliosis was significantly correlated with study level. Female students in physical therapy programs are more likely to acquire scoliosis than male students in various levels of study [57].

After a year, Sugai K. et al. examined if laypersons' visual categorization of kyphosis adequately predicts future activities of daily living (ADL) deterioration. This research was part of the Kurabuchi research, a group of older people Japanese community residents. Using source drawings, three non-specialist assessors classified 532 people without ADL decrease at the beginning into four groups during 2009 and 2010. Additional observers employed curve ruler, SM, and block techniques to evaluate kyphosis in the same patients. Deterioration in ADL was measured by Katz Index dependency, nursing home admission, or long-term care certification. The visual inspection identified 35 subjects (6.6%) initially with the most severe kyphosis. High interrater agreements (Kappa = 0.73) for the most challenging group. ADL reduction occurred in 106 individuals (19.9%) during 4.5 years. Based on visual evaluation, the most significant kyphosis individuals had an altered risk ratio for ADL deterioration of 2.6 (95% CI: 1.4–4.6). Using the SM, kyphosis evaluations reliably expected ADL deterioration. In this research, kyphosis visual evaluation expected ADL decreases. This strategy, which does not need specific instruments or guidance, could recognize individuals at high risk of ADL deterioration [58].

Three years later, Azevedo N. et al. examined the correlation between sagittal spine posture angles and stable equilibrium. 2019, a cross-sectional survey was undertaken with kids and teenagers from northern Portuguese schools. An online questionnaire was employed to characterise and analyse back discomfort in the participants. The SM was used for pelvic, lumbar, and thoracic spinal posture angle measurement, whereas Namrol® Podoprint® was used for stabilometry testing. Statistical significance was determined at α = 0.05. Findings indicated females had more vital balancing factors. A slight association exists between anthropometric measures, stabilometry parameters, and posture angles. Most correlations, save for the thoracic and lumbar spines with anthropometric characteristics and BMI, are harmful. Findings indicate that spine posture angles are not accurate indicators of stabilometric parameters. Raising the thoracic spine's posture angle improves the chances ratio of back discomfort by 3% [59].

After a year, Cepková A. et al. want to examine the disparities in spine curvature between male and female sedentary university students. Forty males inactive university students, with an average age of 20 ± 1.08 years and twenty passive females, with an average age 20 ± 0.73 years participated in this study. When standing and seated, SM assessed their lumbar and thoracic curves. Eighty per cent of the females and sixty-nine per cent of the men had balanced thoracic spine postures (33.25˚ and 35.33˚, respectively) when they stood. A higher proportion of men (30.8%) had hyperkyphosis (54.27˚ vs. 47.0˚) compared to females (10.0%). The research found that 10.0% of females had hypokyphosis, with an average angle of 18.50˚, whereas no men had hypokyphosis. A balanced lumbar spine position was observed in 97.4% of males and 90.0% of females (-33.11˚ and -29.76˚, respectively). Only 2.6% of men and 10.0% of females were found to have hyperlordosis, with a range of -41.0˚ and -50.0˚, respectively. Neither the male nor female individuals exhibited hyperlordosis. When seated, 70.0% of females and 33.3% of men had a normal thoracic spine posture, 30.20 degrees for females and 30.62 degrees for males. Thirty per cent of the females (47.50˚) and twenty-three per cent of the men (46.67˚) had mild hyperkyphosis, whereas forty-six per cent of the men (59.76˚) had hyperkyphosis, and none of the females had it. Also, 70.0% of females and 38.5% of males had balanced lumbar spine positions (7.0˚ and 6.6˚, respectively). A minor hypokyphosis was observed in 35.9% of males and 5.0% of females (16.14˚ and 16.0˚, respectively). About 25.6% of men and 25.0% of females had somewhat greater hyperkyphosis; 25.6% of men had 23.9 degrees and 22.5 degrees, respectively. Significant disparities in spine curvature exist between genders. Men had problems with their thoracic spines for sitting and standing, whereas women only had issues with their lumbar spines when standing. It is critical to ensure that college students have proper recovery strategies to avoid spinal abnormalities from sitting for lengthy periods in class [60].

At the same year, Shehada M. et al. studied the incidence of anomalies and their correlation with age, body mass index (BMI), and physical activity in undergraduate men in Tehran universities. A research of 400 Tehran University of Medical Science undergraduates examined the link between postural disorders and related variables. Individuals' demographics, physical activities, and spinal curvature were measured via questionnaires, SM devices, and photographic mapping. Statistical analysis was conducted utilizing IBM SPSS version 22 and a Pearson correlation coefficient to analyze parameter relationships. Postural anomalies were frequent in the research, with forward head posture (FHP) (84.5%) being the most common, followed by lumbar lordosis (79.8%) and posterior kyphosis (34.7%). Postural anomalies were substantially linked to criteria including age, BMI, waist-to-hip ratio, and physical activity. Research on male undergraduates found that FHP, posterior kyphosis, and lordosis are prevalent postural disorders with variable degrees of prevalence. FHP was a widespread anomaly. The incidence of postural abnormalities was associated with age and BMI, with kyphosis being increasingly prevalent in pupils under the age of 18. A substantial correlation exists between BMI and postural anomalies, whereas physical activity is linked to FHP prevalence [61].

In parallel, Azevedo N. et al. examined back pain prevalent in kids and teenagers, identifying hazards and protecting variables. Cross-sectional research of 1463 9–19-year-olds of both sexes was done in northern Portuguese schools from October to December 2019. The study employed the SM for postural assessment, Inbody 230® for body composition, an online questionnaire for back discomfort, and the FITescola® battery test for physical activity. 50% of respondents had back discomfort at least once. Lumbar and thoracic spine discomfort was often cited, from mild to severe. Variables such as age, female sex, body obesity, extended smartphone/computer usage, hyperkyphosis, and left global spinal inclination increase the likelihood of back discomfort. Consistent participation in sports or physical activity, as well as online gaming, confer a protective influence. The research highlights the significant frequency of back pain in kids and teenagers, highlighting preventive variables like physical exercise and video games and hazard variables like body obesity, extended smartphone or computer usage, and postural [62].

Additionally, at this time, Zaborova V. et al. investigate the connection between seniors' kyphosis, anomalies of lumbar lordosis, pain, and quality of life (QoL), and physical activity (PA) as determined by accelerometer. The participants in this cross-sectional research were 163 elderly Russians, with 73 of them being female. Their ages ranged from 65 and above, and their mean age was 68.70 ± 3.09. Researchers measured PA with ActiGraph wGT3X-BT, kyphosis and lumbar lordosis anomalies with SM, and using the WHOQOL-BREF survey to measure quality of life. Two questions were used to determine the degree of discomfort. The data was analysed using independent t-test and regression analysis. As indicated by the findings, the participants' mean daily moderate physical activity (MPA) of 15.8 minutes was below the suggested recommendations. Males were substantially more physically active than females. Additionally, MPA was linked to reduced kyphosis, lumbar lordosis anomalies, and discomfort in older people. MPA was substantially related to improved quality of life. These data suggest that PA is a significant issue for seniors. Physical educators and fitness instructors should encourage an active lifestyle among seniors using suitable tactics [63].

**2.6 The efficiency of exercises on spinal alignment**

In 2016, Topalidou A. et al. examined spine shape and movement in individuals who had decompression and posterior fusion using pedicle screws. Twenty people who had received posterior fixation for lumbar spine fusion at one or two levels were a part of the research. The control group included 39 healthy individuals. Spinal mobility and curvatures were assessed using the non-invasive SM technology. Visual Analogue Scale (VAS) measured pain. The Oswestry Impairment Index (ODI) and the Short Form-36 were used to assess functional impairment and standard of living. Evaluations were conducted prior to and following the surgical procedure at three-, six-, and twelve-month intervals. The sagittal mobility of the lumbar spine showed significant improvement (p = 0.009) over 12 months in comparison to 3 months. Following a period of 12 months, there was a substantial improvement in the mobility of the thoracic spine in the frontal plane (p = 0.009) as compared to the examination conducted before the surgery. The VAS, ODI, and SF-36 PCS scores significantly rose (p<0.001). There was a strong and substantial correlation between fusion levels and whole trunk tilt in an upright position (r = 0.651, p = 0.002). Although the treatment group exhibited significant improvements in pain reduction, quality of life, and spinal mobility, they still had limited movement and lower curvature/angles compared to the control group [64].

The following year, Çelenay Ő. et al. looked into how an eight-week thoracic stability exercise plan changed the back discomfort, spinal alignment, posture sway, and core fitness among college students. The experiment included 28 students in the experimental category and 25 in the control category, who were chosen at random. The fitness regimen spanned eight weeks, with sessions occurring three times each week. At the beginning and conclusion of the eight weeks of training, participants were evaluated for postural pain, spinal alignment, sway, core endurance, and SM. Additionally, McGill's trunk muscular endurance tests and the Biodex Balance System were used. Between the first assessment and week 8, the training group demonstrated noteworthy variations in postural discomfort, dynamic stability index (with the eyes closed), lumbar and thoracic curvature, and core capacity ratings. These alterations were statistically significant (P < 0.05) compared to the control group. This method improved core endurance in undergraduates while reducing postural discomfort, spinal curvatures, and sway. The training may help relieve pain resulting from improper posture, spinal misalignment, impaired core function, and instability issues [65].

Also at once, Beratto L. et al. tested the impact of micro-loads and elastic band exercises on individuals with Parkinson's disease (PD). Twenty-one PD patients were studied. All subjects walked unaided, with an impairment rating of 2 ± 0.5 on the Hoehn & Yahr scale. Participants were selected at random to either the micro-loads category (11, 69 ± 10 years old; weight 72 ± 12 kg, height 171 ± 7 cm) or the elastic band category (9, 70 ± 11 years old; weight 69 ± 15 kg, high 169 ± 9 The two types exercised twice a week for five months. Flexibility, body equilibrium, spine form, and lower limb strength were assessed using sitting and accessibility, stabilometric platform, SM, and sitting-to-stand tests. The training regimen included three examinations: following the first and third months of physical activity and at the conclusion of the training period. A substantial change in the sit-to-stand test was seen in the EG category (T0 versus T2; Anova, p < 0.001, post hoc, p < 0.01, +19%) and endured micro-loads and elastic band workouts. Elastic band workouts significantly improved lower limb muscle function [66].

In 2021, Coscia F. et al. conducted a study to evaluate the effectiveness of AeLASTIC training in enhancing proprioception and posture. The participants engaged in a 20-minute exercise session twice a week for two weeks. This pilot research included a cohort of 24 physically fit students (aged 18-25) from the Department of Medicine and Surgery-Sport Science at Perugia University. The participants, consisting of both males and females, were divided into two groups of twelve students each, without any specific criteria for grouping. Category A was recommended to engage in a 20-minute aeLASTIC workout twice a week for two weeks. The study's scientific rigor was maintained by the SM, who evaluated all participants using repeatable, non-invasive, efficient methods and provided immediate feedback. Two evaluations were administered at the commencement of the class and again after 45 days. The testing included evaluating two measures during a Mathias test: one of the total regions in sagittal posture and the other, specifically of the lumbar area, in the same stance. The results were compared between Category A, which consisted of individuals who engaged in aeLASTIC training, and Category B, which served as the control group. In order to collect data, a Student's t-test with two tails was used. Pairwise Student's t-tests were used to analyze the variances. The statistical significance was deemed acceptable at a probability level of 0.05. The data underwent processing using SPSS statistical software, specifically version 22.0 (SPSS Inc., Chicago, IL, USA). Research comparing Category A (aeLASTIC training) and Category B (controls) revealed substantial differences in post-test results (P = 0.0001). Total exercise improves during Mathias test. Category A and Category B improved the lumbar area during the Mathias test. Data analysis reveals a more significant reduction in the lumbar portion in Category A (aeLASTIC training). Twenty minutes of aeLASTIC exercise twice weekly in an orthostatic position improves spine, posture, and abdominal muscle activation for two weeks [67].

Parallel to that, Kocaman H. assessed how well two exercise regimens worked for teenagers with idiopathic scoliosis. Two categories were randomly allocated to a total of 28 patients with intermediate adolescent idiopathic scoliosis (10˚-26˚): the core category (n = 14) and the Schroth group (n = 14). The participants in the Schroth and core groups had supervised Schroth and core stabilisation exercises for ten weeks, in addition to different traditional workouts. The Cobb angle was evaluated using radiographic; the trunk rotation was assessed using Adam's exam; cosmetic trunk malformation was evaluated using the Walter Reed Visual Assessment Scale; spinal mobility was assessed using the SM; peripheral muscle strength was evaluated using the Bio-dex System 4-Pro, and The Scoliosis Research Society-22 questionnaire was used to measure quality of life. Individuals in the Schroth category showed significantly more significant gains in Cobb angles, cosmetic trunk deformities, spinal movement, and quality of life compared to those in the core group (p<0.05), except for the lumbar trunk rotation angle. With a p-value less than 0.05, the core group showed significantly more significant peripheral muscular strength increases than the Schroth group. In moderate adolescent idiopathic scoliosis modification, Schroth activities are more effective than exercises for core stability, whereas core stabilisation activities contribute more efficiently to developing peripheral muscle strength [68].

Likewise, at the exact moment, Szigethy M. et al. developed neglect behaviour in pubertal youngsters via intervention. The program examined the spine column's primary function and the strength and extensibility of posture-related muscles. The experiment focuses on 7th-grade students from Neumann János Primary School in Szombathely, Hungary. Seven students are in the nb group, and ten are in the ng group. Before and after the programme, the function of the spine column and physiological curvatures were examined using the Idiag M360 SM. Following the Matthias test, the gadget assessed the children's spinal health while standing, bending forward, and standing again. A reduction in all variables and a rise in the sacrum-to-hip ratio (Sac/Hip) from 9.83±4.36 to 21.63±4.39 (p<0.000) were seen in the findings from treatments (1) and (2). The most notable change occurred in the angles of the dorsal vertebral bodies of Th11/12, with a decrease from 4.50±2.05 to -0.30±0.25 (p<0.000). Pelvic inclination and lumbar lordosis curvature decreased to levels commensurate with the patient's age after the postural rehabilitation programme [69].

Additionally, Özsoy İ. et al. looked into the relationship between spinal mobility and unsupported upper extremity exercise capacity (UUEEC) as well as whether or not spinal mobility predicts UUEEC. The study recruited 40 asymptomatic participants (mean age=21.50±1.51 years, 52.5% female). The UUEEC was assessed using a 6-minute pegboard and ring test (6PBRT). The evaluation of spinal mobility is performed using computer-assisted electromechanical equipment known as the SM System, developed by Idiag in Fehraltorf, Switzerland. The assessment of spinal mobility was conducted in the sagittal plane, measuring the maximum extension and flexion, as well as in the coronal plane, measuring the full lateral flexion to the left and right. Mobility of the spinal cord was positively associated with 6PBRT grade (r=0.361, p=0.022) and CRP (r=0.322, p=0.043). The spinal mobility of the patients with SAP was shown to be a significant and independent factor in determining the 6PBRT grade. In fact, it accounted for 11% of the variance in the stepwise multiple linear regression analysis. The spinal mobility of individuals without symptoms may be used to predict UUEEC in SAP. This study indicates that enhanced spinal mobility positively impacts upper extremity exercise capacity (UUEEC) [70].

Additionally, Kuligowski T. et al. evaluated the effectiveness of stabilizing exercise for the deep core muscles of the lumbar spine in individuals with degenerative disc degeneration. In this investigation, 38 individuals participated. Subjects were split into extrusion (EXT, n = 17) and protrusion (PRO, n = 21). All patients undertook a four-week core stability training regimen (five sessions/week). Clinical outcomes were measured before, after, and four weeks following the intervention. Oswestry Disability Index (ODI) and spinal ROM were the critical outcome measures. The SM instrument was used to evaluate the ROM of the spine. During monitoring, the ROM in the PRO group dropped from 88.52◦ to 83.33◦, and it dropped even lower to 82.82◦ following the intervention. A p-value of less than 0.01 indicates statistical significance for this shift in ROM. After the intervention, the ODI dropped from 16.14 points to 6.57 points, dropping even further to 9.42 points during monitoring with a p-value of less than 0.01. During the intervention, the EXT group reduced the ROM from 81.00 degrees to 77.05 degrees. Subsequently, it climbed to 77.94 degrees during the follow-up period. This change was statistically significant, with a p-value of 0.03. Alternatively, after the intervention, the ODI dropped from 22.58 to 15.41 and hit 14.70 during monitoring (p < 0.001). Although the clinical outcomes in each group improved due to the stabilising physical activity sessions, it is not feasible to conclusively ascertain whether the specific kind of intervertebral disc damage significantly affects the effectiveness of stabilising activity-based treatment [71].

In 2022, Colati R. et al. analyzed vertebral column flexibility utilizing the SM (Idiag, Volketswil, Switzerland), which spatially surveys a vertebra's location. Data were taken prior to and following osteopathic therapy in various spinal column locations on healthy individuals. Believed osteopathic therapy would increase spinal column flexibility. The exposed spinal column was utilised to obtain measurements while standing, statically bending, dynamically bending, and performing the static Matthiass test of balance with extended arms and a 1 kg load. Spinal inclination degrees and altitude fluctuations (mm) were assessed before and after osteopathic treatment under specified conditions. While in an upright position, there were significant enhancements seen in the inclination of the spinal column (measured in degrees) and the length of the vertebral metameres (measured in millimetres) (T<0.04 and T<0.04, respectively). An overall increase in inclination was seen during static bending, specifically in the thoracic region during the Matthias test, with statistical significance at a significance level of less than 0.05 and 0.02, respectively. The study revealed that osteopathic treatment significantly enhanced spinal flexibility in several scenarios, including inclination (measured in degrees) and length (measured in mm). [72].

Simultaneously, an investigation was conducted by Najafi Ghagholestani B. et al. to determine whether joint aquatic exercises (AEs) and dynamic-neuromuscular-stabilisation (DNS) could alleviate pain, impairment, lumbopelvic control (LPC), and spinal posture in patients suffering from non-specific LBP (NSLBP). Forty-five people were divided into three groups at random for this study: 15 DNS, 15 AEs, and 15 control subjects. Pressure biofeedback, an SM device, the visual-analogue scale (VAS), and an Oswestry impairment questionnaire were used to assess LPC, spinal position, pain level, and impairment both before and six weeks after rehab. No support was provided for the control group. The treatments did not have a statistically significant impact on the improvement of pain or impairment across the study groups (P>0.05). Additionally, there was no significant variance in LPC dysfunction improvements between the AEs and DNS groups (P>0.05). Significant improvements in spinal tilt (P=0.03) and ROM (P=0.05) were only seen with AEs. Findings indicate no considerable variance between DNS activities and AEs in improving discomfort, impairment, and LPC. If access to pools and hydrotherapy pools is limited, different methods may be employed to enhance malfunctions [73].

After year ago, Domokos B. et al.evaluated the immediate effects of isolated lumbar extension resistance exercise (ILEX) on spinal posture and mobility. This study employed an interventional cohort design to assess the posture and mobility measurements of a sample of 33 healthy persons. The SM system (IDIAG M360©, Fehraltdorf, Switzerland) was used to evaluate these variables. Participants engaged in a single about of exercise until complete muscular fatigue using an ILEX device (Powerspine, Wuerzburg, Germany) inside a controlled environment that ensured a consistent ROM and duration of muscular contraction. Scans were conducted both prior to and following the workout session. An abrupt and substantial reduction was observed in the degree of standing lumbar lordosis and thoracic kyphosis. There was no discernible alteration noticed in the standing pelvic tilt. The results of the mobility assessments indicated a notable reduction in lumbar spine mobility and a corresponding rise in sacral mobility. According to the results, ILEX may improve spinal mobility and posture in a short amount of time, which might be beneficial for certain patient groups [74].

In parallel, Amiri B. et al. investigated how diaphragmatic breathing techniques affected stable posture and fatigue-induced spine movement in older, sedentary Individuals who have had chronic and widespread low back pain (LBP). Twenty inactive individuals aged 25-44 will apply Abt's exhaustion procedure, which includes active recovery (diaphragmatic respiration exercises) and passive recovery (lying in bed). One week of relaxation will be taken between. Spinal movement and stable posture will be assessed utilising an SM device and posturography system during and after active and passive recovery. Electromyography (EMG) will assess muscular exhaustion. In inactive individuals, active recovery using diaphragmatic respiration practices may be more successful than passive recovery in recovering spinal movement, stable posture, and back and hamstring muscle exhaustion. Strengthening core and respiratory muscles with these workouts may improve spine stability and movement. Reducing compression on passive spine components may also help reduce LBP. Diaphragmatic respiration practices may improve back health in inactive mature persons and can be integrated into job duties [75].

**2.7 Other factors**

In 2015, Masaki M. et al. examined the relationship between sagittal orientation of the spine, muscle thickness, and muscle echo intensities. These measures quantify the lumbar back muscles' bulk and non contractile tissue. The study included a sample of thirty-six women who were middle aged and older. Ultrasonic imaging was used to assess the psoas major, lumbar multifidus, and erector spine muscles' thickness and echo intensity. The SM has made it easier to measure thoracic kyphosis, sacral anterior tilt, lumbar lordosis, and alignment of the spine in the sagittal plane. A detailed regression analysis was conducted using age, echo intensity, and muscle thickness as independent variables. The results showed that the angle of thoracic kyphosis was significantly affected by the thickness of the erector spinal muscle. The amount of sacral anterior tilt was greatly affected by the psoas major muscle's size and the lumbar multifidus muscle's echogenicity. When the pelvis tilts backwards, the psoas major muscle mass decreases and the lumbar multifidus muscle's non-contractile tissue increases. There was a decrease in the bulk of the erector spinae muscles because to their developing thoracic kyphosis [76].

After two years, Masaki M. and colleagues assessed the correlation between low back pain (LBP), spinal alignment, lumbar muscle mass, and muscular stiffness as determined by ultrasonic shear wave elastography (SWE) in individuals who were young to middle-aged medical professionals. Nine medical personnel with LBP comprised the LBP cohort, while twenty-three were asymptomatic (CTR cohort). The mass and rigidity of the lumbar back muscles, which comprised the quadratus lumborum, multifidus, and erector spinae, were evaluated by ultrasonic (SWE). Simultaneously, the individual was lying in a supine posture. In addition, a sagittal alignment of the spinal column assessment was conducted utilizing an SM in both upright and lying situations. Researchers conducted a multivariate logistic regression analysis to examine the association between LBP and prospective selection.The study conducted a separate analysis of many features, including the shear elastic modulus, thickness, alignment of the spine, age, body height, weight, and gender of the lumbar back muscles. A subject's length and the rigidity of the lumbar multifidus muscles were shown to be significant separate variables linked to LBP in multiple logistic regression studies. Nevertheless, no substantial impact was seen on LBP due to muscle mass and spinal alignment. The difference in lumbar multifidus muscle stiffness was statistically significant when comparing the LBP and CTR groups. This research found that lumbar multifidus muscle stiffness is associated with LBP among middle-aged and younger medical professionals [77].

Also, in the same period, Taspinar F. et al examined the relationship between body composition and spine alignment in healthy teenagers. The research included 67 healthy participants aged 18-25 (37 males and 30 females). For every person, SM (Idiag, Fehraltorf, Switzerland) measured the lumbar and thoracic sagittal spinal curvatures. The body content (total fatty tissue, whole muscles, visceral fat, and body muscle levels) was estimated using bioelectrical impedance by means of the Tanita Bc 418 Ma Segmental Body Composition Analyzer (Tanita, Japan). The parameters were examined using Pearson's correlation. The mean lumbar lordosis and thoracic kyphosis angles were 21.02°±9.39 and 41.50°±7.97, respectively. An evident and statistically significant correlation (r=0.28, p=0.02) was seen between the proportion of total fat and the angle of lumbar lordosis. An advantageous correlation was discovered between the ratio of visceral fat and the angle of lumbar lordosis (r=0.27, p=0.03). The angle of thoracic kyphosis showed a favorable correlation with both the ratio of total fat (r=0.33, p=0.00) and the ratio of visceral fat (r=0.40, p=0.01). The overall proportion of muscles exhibited a negative correlation with lumbar lordosis (r=-0.28, p=0.02) and thoracic kyphosis angles (r=-0.33, p=0.00). Still, no significant correlation was seen with trunk muscle ratio and lumbar and thoracic curvatures (p>0.05). The study revealed that an increased fat percentage and a decreased proportion of abdomen or body muscles might modify the posture of the spine and have an adverse effect on spinal loading. Therefore, spine rehabilitation must include the analysis of body composition [78].

In 2019, Piancino M. et al. compared thoracic-lumbar-sacral spine posture and cephalometric data in both sets of people with varying cranial structures in the sagittal plane. Based on the location of the condyle-orbital plane (CoOr) about the superior maxilla (SpP), the research divided the 81 participants into two groups: 49 subjects in group 1 (11.6 (2.1) years) showed CoOr posterior rotation: SpP^CoOr ≤ -2°, -4.1% (2.1°); 32 individuals in group 2. The average age of individuals with anterior-rotation of the CoOr is 12.9 (2.3) years. The degree of rotation, measured as SpP^CoOr, is equal to or more than 2°, with an average value of 3.7° (1.9°). Patients received blinded SM keeping records and skull cephalometry. The first cohort had a significantly greater forward spine incline (4.4°(1.8°)) compared to the second cohort  (2.4°(1.3°)) (p < 0.0001), and more excellent skull vertical dimensions (maxillary divergency, steep occlusal plane, gonial angle) (p < 0.001). This research found a variation in thoracic-lumbar-sacral spinal tilt across categories with varying craniofacial shapes. Achieving this goal enhances collaborative assessment and treatment planning [79].

Following one year, Ito A. et al. investigate the correlation between spinal alignment and muscle thickness alterations in three different positions among seniors without health issues. SM measurements were taken to assess spinal alignment, while ultrasound measurements were used to evaluate the trunk muscles. These measures were conducted on healthy older persons residing in the community in three positions: standing, upright, and slump sitting. When adopting the recession sitting posture, The findings indicated notable variations in spinal alignment based on the angles of lumbar curvature, sacral tilt, and overall tilt. Muscle thickness also varied significantly whether people sat erect, slumped, or stood compared to when they were seated. The thickness of several muscles went when people sat upright vs. slumped, with the 2nd lumbar spinal proprioceptive muscle especially showing variation. In conclusion, the two changes were not related. The idea was put forward that the spine should not be broken down into its parts but rather seen as a whole, with variations in muscle thickness considered [80].

Precisely at the instant, Boroojerdi M. et al. examined whether riders with various riding styles have varying spinal curvature modifications. This empirical research selected 48 male volunteers and 16 professional road bicycle riders, 16 speed bicycle riders, and 16 others as controls. This cross-sectional investigation used an SM to determine the thoracic and lumbar curvature angles while the participants were standing. The typical angles of thoracic kyphosis and lumbar lordosis for top road bicycle riders were 48.3±7.2º and -20.3±7.2º, respectively. For speed bicycle riders, the average thoracic kyphosis angle was 46.6±8.1º and -22.5±7.7º, while for the control cohort, the average thoracic kyphosis angle was 37.5. Compared to the controls, road and racing cyclists they exhibited significantly greater thoracic hyperkyphosis posture (p<0.05) during the research. No road bicyclists had substantially greater thoracic angles than sprint riders (p>0.05). However, all bikers and control categories had appropriate lumbar lordosis angles. The research found that professional cyclists may be at hazard for hyper-kyphotic posture. Road riding may lead to hyper-kyphosis owing to prolonged flexion [81]. Table 4 illustrates the summarization of systematic studies

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| --- | --- | --- | --- | --- |
| **reference**s  **TABLE 4.** Factor, cases, measured parameters, and outcome for studied spine deformity and SM validity. | **FACTORs** | **Cases** | **measured** **parameters** | **outcomes** |
|  |  |  |  |  |
| [26, 27, 28, 29, 30, 21, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40] | Pathological factors | -Fractured vertebrae  -Locomotor syndrome (LS)  -Urinary incontinence (UI)  -Chronic neck pain (CNP)  -Femoroacetabular impingement (FAI)  -Hip osteoarthritis (OA)  -Obstetrical brachial plexus palsy (OBPP)  -Double crush disorder  -Chronic obstructive pulmonary disease (COPD)  -Lumbar spinal stenosis (LSS)  -Unilateral posterior crossbite (UPC). | The structure, positioning, mobility, and functioning of the spinal column in individuals with a condition that impairs the spinal. Furthermore, the degree of spinal misalignment, such as the impact of an increased kyphosis angle on a specific illness. | These studies facilitated the diagnosis of the impact of these diseases on the spine and their underlying causes, thereby enabling the identification of a suitable treatment to alleviate the symptoms. Additionally, they helped determine whether physical therapy or rehabilitation is necessary following the spinal realignment surgery to enhance its functionality and mobility. |
| [41, 42] | Non-pathological factors | Pregnancy and the menstrual cycle. | Spinal Caspostural alterations, level of anxiety, ability to move, positional proficiency, and ability to stabilise. | These investigations have discovered that pregnancy may cause alterations in the curvature and alignment of the spine, resulting in pain as well as the curvature of the spine that indicates lumbar kyphosis in pregnant women. This data serves as a foundation for investigating the impact of spine curvature and postural alterations on pregnant symptoms. Anxiety, spinal posture, mobility, and postural competence did not alter significantly over the menstrual cycle. However, menstrual cycles resulted in a reduction in dynamic stability. Gaining insight into the impact of menstrual cycles on dynamic stability may aid in preventing accidents among physically active females. |
| [43, 44] | School children's spine. | Inappropriate posture in school children and factors such as back pain, spinal mobility, alignment, and physical fitness. | These studies demonstrated the efficacy of the SM device in assessing bad posture in young children. At the same time, school assessments provide qualitative outcomes and are not used for evaluating the problem. Moreover, a correlation exists between elevated physical fitness levels and heightened pelvic tilt and spine tilt in young children. Males exhibiting low levels of aerobic activity had postural insufficiency. |
| [15, 45, 46, 47, 48] | Check the SM gadget's accuracy. | The reliability of the SM, a novel, noninvasive, computer assisted wireless telemetry device utilized for quantifying spinal curvatures, movement, and functionality in healthy and ill individuals. | These investigations showed that the SM device had great intrarater accuracy when evaluating sagittal, thoracic, and lumbar spine deformation and flexibility. Nevertheless, its performance was notably unsatisfactory in the frontal plane. |
| [49, 50, 51, 52, 53, 54, 19] | Compare the SM to other measurement methods. | The effectiveness of the SM in relation to various measuring approaches, including radiological methods such as the Cobb angle determined using an X-ray device and non-radiological methods like the Back Mapper, Flexicurve, Arcometer, and finger-floor distance measurements. | The outcome of this research indicated that curves with an angle over 40° demonstrated higher accuracy in Cobb and SM measurements. An extremely significant correlation was seen between the results collected using Cobb and SM techniques (p < 0.0001). Further study is required to evaluate the precision of non-radiographic techniques via the establishment of clinically meaningful standards. |
| [55, 20, 56, 57, 58, 59, 60, 61, 62, 63] | Incorrect posture, obesity, smartphones/PC, age, and gender. | The correlation between spinal deformity and many variables that influence its alignment, including age, gender, obesity, extended use of smartphones and computers, and incorrect positioning of the spine when sitting or walking. Also, diseases associated with age and those influenced by gender, such as scoliosis, exhibit a higher incidence among women or men, depending on the case. Additionally, kyphosis, which indicates a decline in daily functioning, is influenced by ageing. | These research findings indicated that factors such as age, gender, adiposity, extended smartphone/computer use, hyperkyphosis, and leftward spinal tilt increase the probability of experiencing back pain. Several studies have shown that female students in physical therapy programs have an increased risk of scoliosis compared to male students throughout different academic stages. Separate research revealed that the thoracic spine causes a disadvantage for men in both standing and sitting positions, but the lumbar spine only impacts females when standing. Research has established a correlation between the occurrence of postural abnormalities and age and body mass index. It was shown that the frequency of kyphosis tends to rise among students below 18 years old.  Furthermore, research has shown that engaging in regular moderate physical activity (MPA) daily might help decrease the occurrence of kyphosis, lumbar lordosis anomalies, and pain among older individuals. The presence of MPA was strongly correlated with enhanced quality of life. The statistics suggest that physical exercise is a significant concern for individuals of all genders and age groups. Using suitable strategies, physical educators and fitness coaches should promote a physically active lifestyle among children, adolescents, and older adults. |
| [64, 65, 66, 67, 68, 69, 70, 71, 72, 73, 74, 75] | Exercises & rehabilitation. | The effectiveness of different exercise programmes in correcting abnormal spinal tilt and curvature. These interventions include micro-loads, elastic band exercises, AeLASTIC training, Schroth activities, a postural rehabilitation program, unsupported upper extremity exercise capacity (UUEEC) diaphragmatic respiration practices, immediate effects of isolated lumbar extension resistance exercise (ILEX), dynamic neuromuscular stabilization (DNS), joint aquatic exercises (AEs), and osteopathic therapy. These interventions are administered for a specific duration and target healthy individuals and those with specific medical conditions. | This research shows that doing aeLASTIC exercise for twenty minutes twice a week while in an upright position enhances the activation of the spine, posture, and abdominal muscles for two weeks. Teenagers with intermediate idiopathic scoliosis respond better to Schroth exercises, even if core stabilisation exercises are more advantageous for strengthening peripheral muscles. According to several studies, lumbar lordosis and pelvic tilt are reduced to age-appropriate levels after a postural rehabilitation programme. Several studies have shown a correlation between UUEEC and spinal motion. Specifically, analyzing spinal motion in the sagittal plane has been identified as a predictor of UUEEC in patients without symptoms. This study shows that increasing spinal mobility can enhance UUEEC.  The findings suggest no notable difference between DNS activities and AEs in improving discomfort, weakness, lumbopelvic control (LPC), and spinal posture in individuals with non-specific LBP. Several studies have shown that ILEX and osteopathic practices notably impact spinal posture and mobility. Additionally, diaphragmatic breathing techniques have the potential to enhance back health in sedentary older individuals and can be incorporated into job duties. |
| [76, 77, 78, 79, 80, 81] | Other. | The correlation between spinal alignment and the following factors: muscle thickness and muscle echo intensity as indicators of lumbar back muscle mass and non-contractile tissue. Furthermore, muscular stiffness, lumbar muscle mass, LBP, body composition, and variations in muscle thickness at three separate sites in individuals from various age groups. Additionally, two groups of individuals with varied cranial characteristics in the sagittal plane had their thoracolumbosacral spine positions and cephalometric data compared. It was also investigated if riders with various riding skills had different adjustments in spinal curvature. | The findings of this study were determined by analyzing the reciprocal relationship between the spine and other parameters, such as muscle thickness and echo intensity, using a progressive regression analysisThe angle of thoracic kyphosis, which in turn influences the angle of the sacral anterior tilt, is significantly influenced by the thickness of the erector spinae muscle. Separate research revealed that LBP is linked to increased stiffness in many muscles of the lower back among medical personnel who are young or middle-aged. Moreover, an elevated fat percentage and a diminished proportion of abdomen or body muscles might alter the spine's positioning and adversely impact the spinal load. The research discovered differences in the thoracolumbosacral spinal tilt across groups with distinct craniofacial forms. Achieving this goal promotes collaborative assessment and treatment planning. Studies investigating the impact of motorcycle riding on the spinal column have shown that elite bikers may be susceptible to hyperkyphosis. Prolonged bending while road cycling might lead to hyperkyphosis. |

# DISCUSSION

As outlined in Table (4), the studies demonstrated the SM's reliability and validity in measuring the spinal column's functionality and evaluating its curvatures across various age groups. The following are the responses to the research inquiries examined in this investigation.

**Q1. What is the method for quantifying spinal deformity?**

Both radiographic and non-radiographic techniques conduct the measurement of spinal alignment and curvature. Radiological techniques include using X-ray and CT scans, which are regarded as very effective procedures for evaluating the spine via measuring the Cobb angle. Non-radiological techniques include a range of tools and measures such as goniometers, spondylometers, scoliometers, kyphometers, digital inclinometers, flexible curve rulers, fingertip-to-floor distance measurements, back mapper, ultrasound (US), magnetic resonance imaging (MRI), tape measuring methods, the Schober index rasterstereography, photogrammetry, and SM Spinal curvature may be evaluated using many techniques; among them, the approach known as SM is considered very reliable and accurate. It is the gold standard for assessing spine alignment and ROM [24].

**Q2.** **What are the variables that influence the morphology of the spinal column?**

Spinal alignment is adversely affected, and the risk of getting back pain is increased by factors such as age, gender, obesity, extended use of smartphones/computers, hyperkyphosis, and leftward tilt of the spine. For instance, research has shown that female students enrolled in physical therapy programs are more susceptible to acquiring scoliosis than their male counterparts at various stages of study. Distinct studies have shown that the thoracic spine is responsible for causing harm to males in both standing and sitting situations, while the lumbar spine impacts females when standing. Empirical studies have shown a correlation between postural abnormalities, age, and body mass index. Evidence indicates that the prevalence of kyphosis is often greater among pupils under 18 years old.

**Q3.** **What non-surgical treatments are used to improve spinal alignment and reduce the effects of age, weight, gender differences, etc.?**

Various exercises may be used to rectify the atypical inclination and curvature of the spinal column. The interventions involve multiple techniques such as micro-loads, elastic band exercises, AeLASTIC training, Schroth activities, postural rehabilitation program, diaphragmatic breathing practices, unsupported from upper extremity exercise capacity (UUEEC), direct effects of isolated-lumbar-extension-resistance-exercise (ILEX), dynamic neuromuscular stabilization (DNS), joint aquatic exercises (AEs), and orthodontic treatment. These treatments are conducted for a particular duration and then assessed to establish the efficacy of the workouts on the spine.

**Q4. Are there any pathological conditions that impact the alignment of the spinal column?**

Numerous biological illnesses may impact spinal health. Some experiments and research studies focused on evaluating and analyzing the structure, position, movement, and function of the spine in individuals with a condition that limits spinal function and consequently affects the entire body. This condition can appear as postural instability, lower back pain, and reduced muscle strength. A separate investigation analysed the sagittal spinal curvature, movement, and occurrence of LBP in both women with and without urine incontinence (UI). The outcome was that the UI necessitated focus on maintaining proper spine alignment in the sagittal plane and minimizing excessive movement of the lumbopelvic [28]. The research compared the thoracic spine curvature and mobility of those without chronic neck pain (CNP). This study has shown that CNP patients tend to have a thoracic curvature above 45 degrees and a decrease in mobility beyond 30 degrees, which may indicate their condition [29]. The researchers also examined lumbar hyperlordosis and ROM in people who had arthroscopic treatment for femoroacetabular impingement (FAI). The researchers discovered that people with FAI had reduced flexibility in the lumbosacral region but did not show any increase in hyperlordosis angles. These results suggest that spinal mobility training in post-arthroscopic and other rehabilitation protocols might be beneficial [30]. One study examined the effects of spinal sagittal alignment on middle-aged and older women's locomotor syndrome (LS) and physical performance. In independent research, medical examinations of middle-aged and elderly adults were used to determine the impact of LS risk factors such as spinal degeneration, muscle strength, physical ability, spinal alignment, and LBP. This research shows that in middle-aged and older women living in the community, the lumbar spine's (LS) health and physical performance are affected by the spine's alignment in the sagittal plane. Also, lumbar lordosis angle (LLA) reduction, increased spinal degeneration, and total spinal imbalance due to anterior spinal tilt were seen in LS patients [27, 32].

Various research enabled the identification of the effects of multiple disorders on the spine and their root causes, therefore allowing for the determination of the suitable therapy to relieve the symptoms. Furthermore, they assisted in assessing the need for physical therapy or rehabilitation after spinal realignment surgery to improve spinal mobility.

**CONCLUSION**

In the last decade, several research initiatives have created technology designed to observe and evaluate the movement and functionality of the spinal column and analyse its curvature. This review research aims to elucidate the effectiveness and accuracy of the SM approach for assessing the spine in different age groups, as shown by the tests and studies previously described. This review article also declares their findings and conclusions so that the rest of the researchers can build on their discoveries in the following years. According to current investigations, this study paper concludes that evaluation of SM is essential for medical applications such as evaluating the efficacy of the spinal function and, in instances, necessitating frequent exams, such as the surveillance of scoliosis.

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**Conflicts of interest**

The authors have not reported any conflicts of interest.

**Author’s contribution statement**

**Esraa K. Mahan:** Responsible for conceptualizing and designing the work, interpreting and analyzing data, and writing and revising the original manuscript. **Aseel Ghazwan:** Supervision, revised the article for important intellectual content and approved the final version of the manuscript. **Luay Asaad Mahmood:** Supervision, and approved the final version of the manuscript.

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| --- | --- | --- |
| **Description** | **Abbreviation** | **S. No.** |
| 6-minute pegboard and ring test | 6PBRT | 1 |
| Activities of daily living | ADL | 2 |
| Body mass index | BMI | 3 |
| Electromyography | EMG | 4 |
| 25-question evaluation called the Geriatric-Locomotive-Function-Scale | GLFS-25 | 5 |
| Intraclass correlation coefficient | ICC | 6 |
| Low back pain | LBP | 7 |
| Lumbar lordosis angle | LLA | 8 |
| Osteoarthritis | OA | 9 |
| Oswestry Impairment Index | ODI | 10 |
| Posterior-Anterior | PA | 11 |
| Physical activity | PA | 12 |
| Photogrammetry | PG | 13 |
| Quality of life | QoL | 14 |
| Range of motion | ROM | 15 |
| Spinal inclination angle | SIA | 16 |
| Spinal mouse | SM | 17 |
| Visual-Analogue-Scale | VAS | 18 |