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Research Article

The reliability of the developed spinal-mouse in evaluating spinal curvatures

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Abstract
This study aimed to assess the interrater reliability of a developed spinal-mouse (SM) instrument for measuring the sagittal and frontal planes, as well as the overall range of motion (ROM) of the spine in patients with degenerative scoliosis (DS) and kyphosis. Measurements were conducted on two groups: subjects with DS, characterized by a spinal deformity exceeding 20° (n = 10), and subjects with kyphosis, defined by a thoracic kyphosis angle of less than 55° (n = 10). The developed SM was used to evaluate the curvature and mobility of the thoracic and lumbar regions in the sagittal and frontal planes during flexion/extension and left/right lateral flexion, respectively. Two examiners performed the measurements on the same day. Interrater reliability was assessed using the intraclass correlation coefficient (ICC), and the results were compared to radiological measurements conducted independently by two orthopedists. For patients with kyphosis and DS, interrater ICCs ranged from 0.783 to 0.985 and from 0.791 to 0.933, respectively, with higher reliability observed in the sagittal plane than in the frontal. The SM measurements and Cobb angle values were consistent between raters 1 and 2, demonstrating excellent interrater agreement, with ICCs ranging from 0.860 to 0.924 for kyphosis and 0.833 to 0.889 for DS. Compared to interrater discrepancies in Cobb angle assessments, interobserver variability using the developed SM was notably lower. The findings suggest that the developed SM is a reliable, effective, and user-friendly tool for clinical studies and patient follow-up in spinal disorders.

Keywords
Interrater reliability, Spinal-mouse instrument, Degenerative scoliosis, Kyphosis, Spinal range of motion (ROM), Intraclass correlation coefficient (ICC).

1.Introduction
The sagittal plane of the vertebral column in a fetus is curved, with an anterior concave shape and a posterior convex shape. An anterior concavity characterises the centre curve of the spinal column. Throughout an individual's lifetime, the thoracic, sacral, and coccygeal sections of the spinal column maintain a fundamental curvature. Secondary convexity is the progressive curvature that develops in the cervical and lumbar spine after birth. In adults, the spinal column exhibits both primary and secondary curvatures when viewed laterally. The primary curvature is referred to as kyphosis, while the secondary curvature is known as lordosis. However, the terms kyphosis and lordosis should be used to describe abnormalities of these curvatures only when applied correctly and within a medical context [1].

Furthermore, age-related muscle loss often leads to musculoskeletal diseases such as kyphosis. Kyphosis is a painful musculoskeletal condition characterized by an abnormal curvature of the spine. It can affect the muscles, tendons, joints, and nerves [2, 3].

In older adults, kyphosis can lead to various physical and psychological health issues, including reduced mobility, loss of physical autonomy, localized pain, depression, and ultimately a diminished quality of life [4]. Furthermore, research has shown that older individuals may occasionally overestimate or underestimate their actual health status [5, 6]. Notably, some older individuals who report no physical abnormalities may still have kyphosis, which significantly contributes to back pain and the decline in quality of life among this population [4]. Additionally, the spine may exhibit a slight curvature in the frontal plane, in addition to the normal curves observed in the sagittal plane. Any lateral deviation of the spine equal to or greater than 10° is considered

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scoliosis. It is important to note that scoliosis is a three-dimensional condition, characterized by both lateral curvature and rotational deformity of the spine [1]. Changes in the structure and appearance of the vertebral body characterise structural scoliosis. A vertebral shape change leads to rotational motion, which is particularly noticeable when the change occurs in the thoracic area of the spine [7]. Scoliosis is a musculoskeletal disorder that can affect individuals of all ages. There are different types of scoliosis based on the age at which it occurs: infantile scoliosis (0-3 years), juvenile scoliosis (3-10 years), and adolescent scoliosis (11 years until skeletal maturity or the first sign of puberty) [8].

There is also a type known as degenerative scoliosis (DS), which develops as a result of aging and occurs after skeletal maturation in a previously healthy spine. Scoliosis often demonstrates degenerative features after age 40 since the combined effects of ageing and the degradation of the spine lead to the development of scoliosis. Additional variables that contribute to the condition include inflammation of the facet joints and disc space narrowing. DS is commonly associated with osteoporosis, particularly in women, as the alterations gradually accumulate, resulting in the spine deforming into a curved shape over time [9].

Radiography is the predominant method used to evaluate and diagnose spine deformities and monitor their progression [10, 11]. Patients with kyphosis, lordosis, or DS must undergo several spine radiographs during their clinical follow-up. Despite the availability of new techniques, such as EOS two-dimensional (2D)/ three-dimensional (3D) vector analysis systems [12], which allow for lower radiation doses, the evaluation of curvatures still relies on the use of the Cobb angle. However, it is essential to note that this method poses a risk of spinal cancer [13–15].

Non-invasive and radiation-free instruments have been developed to objectively evaluate physiological spinal curvatures, assess abnormalities, and perform measurements across the superficial layers of the skin. The most widely recognized tools include the inclinometer, electrogoniometer, kyphometer, 3D ultrasound, rasterstereography, computer-aided systems, and photogrammetry [16–19].

The spinal-mouse (SM) is a non-invasive, external device that has been designed to assess the curve and angle of the spine in both the frontal and sagittal planes. The spine's range of motion (ROM) is another measurement it takes [20–23].

The developed SM has not been employed in any investigations to assess abnormal spinal curvatures, including kyphosis and DS. The objective of this investigation was to evaluate the reliability and precision of the SM device by comparing the results to the Cobb angle and designing and developing it. The goal was to assess the ROM and spinal curvatures in the sagittal and frontal planes of individuals with DS and kyphosis.

The rest of the paper is organized as follows. The literature review is presented in Section 2. Materials and methods are described in Section 3. Results are demonstrated in Section 4. The findings are discussed in Section 5. Finally, the conclusion is provided in Section 6.

2.Literature review

Numerous studies have examined the reliability and validity of SM in individuals without reported pain. The primary and most extensive investigation was carried out by Post and Leferink [24] who evaluated 111 people to assess the same-day inter-rater reliability for global and segmental ROM in spinal flexion and extension. Despite global flexion and extension demonstrating exceptional reliability, with intraclass correlation coefficients (ICCs) of 0.95 and 0.92, respectively, there was inadequate agreement ($\kappa = 0.22$) in identifying when segmental flexion and extension values deviated from the normalized values supplied by the computerized system.

Subsequent research has largely corroborated the initial findings of Post and Leferink [24]. The between-day intra-rater and inter-rater reliability of global and segmental spinal ROM evaluation using the SM device has been assessed in two studies involving 81 children and 20 adults. These studies reported comparable ICCs, indicating strong reliability for global ROM evaluation, with pooled intra-rater ICCs ranging from 0.57 to 0.96 and inter-rater ICCs ranging from 0.62 to 0.94 [25, 26]. Both investigations also reported similar standard errors of measurement (SEM) for spinal ROM, typically between 10% and 15%, though occasionally exceeding 20% [25, 26]. While consistently high reliability has been demonstrated for global spinal ROM evaluation using the SM device, notable variability in reliability has been observed in segmental spinal ROM assessments [25, 26].

Mannion et al. [25] revealed that the intra-rater and inter-rater reliability for segmental flexion varied from poor to good, with reliability coefficients ranging from 0.39 to 0.90 and 0.28 to 0.81, respectively. The standard error of the mean for these measurements averaged 2.3°.
Zafereo et al. [27] conducted a study to evaluate the reliability of spinal ROM assessment using an SM device. The study included 20 individuals with low back pain (LBP) and 20 adults without LBP, matched by age and sex. The researchers evaluated both intra-rater reliability on the same day and inter-rater reliability. Global thoracic and lumbar flexion and extension end-range motion assessment in patients with LBP showed fair-to-high intra-rater reliability (ICC = 0.76-0.96) and good-to-high inter-rater reliability (ICC = 0.82-0.98). Interrater reliability for segmental lumbar flexion assessments in individuals with LBP was fair to high (ICC = 0.77-0.93). No notable variations were observed in global thoracic and lumbar flexion or extension end-range mobility between people with and without LBP.

Livanelioglu et al. [28] executed a study to evaluate the reliability and accuracy of Cobb angle and SM measurements in individuals with adolescent idiopathic scoliosis (AIS). The study included fifty-one patients with AIS who received conservative treatment. Two physiotherapists evaluated frontal plane curvatures utilizing SM, and the results were compared with radiography data. Two orthopaedic surgeons performed radiographic assessments. The interobserver and intraobserver reliability of the Cobb and SM measurements was exceptional (ICC = 0.872–0.962). When comparing the assessment discrepancies, the interobserver standard deviation (SD) of measurement differences was lower than the interobserver Cobb angle discrepancies ($p = 0.003$). The concordance between the Cobb and SM readings was more excellent for curves over 40°. A robust or powerful correlation has been identified between measures obtained using the Cobb and SM techniques ($p < 0.0001$).

Roghani et al. [23] undertook a study to evaluate the interrater reliability of the SM in assessing standing sagittal curvature and total spinal mobility in older women, both with and without hyperkyphosis. Measurements were performed on 19 women with hyperkyphosis (thoracic kyphosis angle ≥50°) and 14 women without hyperkyphosis (thoracic kyphosis angle <50°). Evaluations were performed by the identical assessor over two days, separated by a 72-hour interval. ICCs ranged from 0.89 to 0.99 in both cohorts. The SEM ranged from 1.02° to 2.06° in the hyperkyphosis group and from 1.15° to 2.22° in the normal group. The minimal detectable change ranged from 2.85° to 5.73° in the hyperkyphosis group and from 3.20° to 6.17° in the normal group. The findings demonstrated that the SM has better intra-rater reliability in assessing sagittal thoracic and lumbar curvature and spinal mobility in older women.

Walaa and Walaa [29] conducted a study to determine the incidence of scoliosis and to investigate the correlation between scoliosis prevalence and the increasing academic level among physical therapy students at Majmaah University, Saudi Arabia. A total of one hundred fifty-two students in physical therapy were evaluated. Ninety-two of the students were female, whereas sixty were male. The SM assessed the curvature of the student's spine in the frontal plane. The prevalence of scoliosis among physical therapy students at Majmaah University was significantly high at 31.5%, particularly among female students, with a female-to-male ratio of 3:1. There was a strong connection between the prevalence of scoliosis and the amount of education among female students. Female physical therapy students are more prone to developing scoliosis than male students throughout various stages of the physical therapy program.

Azevedo et al. conducted a study in 2022 [30] to investigate the correlation between spinal postural angles in the sagittal plane and stable static balance and, in 2023 [31], to find out the prevalence of discomfort in the back. A cross-sectional study was performed in 2019 with 1463 children and adolescents from schools in northern Portugal. The SM was utilized to evaluate posture. The findings indicated that spinal postural angles are inadequate predictors of stabilometric factors. Regarding back pain, elevating the postural angle of the thoracic spine raises the odds ratio of experiencing back pain by 3% [30]. Fifty per cent of the participants encountered back pain at least once during their lifetime. The lumbar and thoracic spines were the most commonly referenced, predominantly associated with mild to moderate pain intensities. Age, female sex, body fat percentage, extended use of smartphones and computers, hyperkyphosis, and left lateral global spinal tilt are all associated with an increased relative risk of back discomfort. Regular engagement in physical activity or sports, as well as video games, confers a protective benefit [31].

Colati et al. [20] analyzed alterations in spine motion utilizing the SM. Measurements were conducted before and following an osteopathic treatment with varying spinal column postures on healthy individuals. The assessment was conducted on the exposed spine in the following postures: standing, static flexion, dynamic flexion, and during the static Matthiass test, which involves sustaining the standing position with arms extended while holding a 1 kg weight. The spinal tilt was assessed in degrees, and height alterations (measured in mm) were observed in the specified postures before and after the osteopathic therapy. Enhancements have been noted in spine inclination (measured in degrees) and in the length of vertebral metameres (measured in millimetres) while in an upright position ($T<0.04$ and $T<0.04$). A general increase in tilt (measured in degrees) was observed during the static bending position ($T<0.05$) and in the thoracic region during the Matthias test ($T<0.02$). The current study demonstrated that osteopathic treatment enhanced spinal mobility in terms of tilt (measured in degrees) and length (measured in millimetres), assessed in various situations.

Popova-ramova et al. [32] evaluated the prevalence of poor posture among schoolchildren by clinical assessment tests and SM software. The evaluation encompassed 840 children across nine basic school classes, utilizing four clinical examinations conducted in a standardized manner, together with SM device software. Test 2 exhibited the highest positivity rate in class 2, whereas Test 1 demonstrated a positivity rate of 75% across the population. The frequency of positive tests across classrooms was insignificant ($p > 0.05$). However, the percentage of total children with positive tests was significant. School screening tests provide only qualitative measurements and are not utilized for condition assessment; however, the SM device is crucial for the early identification of poor posture in schoolchildren.

Topalidou et al. [33] evaluated the test-retest reliability of the SM for assessing spinal curvatures, mobility, and functionality. The test-retest reliability was evaluated in 50 persons experiencing back or lower back discomfort. Twenty-four characteristics were examined in the sagittal and frontal planes. In the sagittal plane, 22 of the 24 metrics demonstrated high and good dependability, whereas only two exhibited fair and poor reliability. In the frontal plane, 17 parameters exhibited high and good dependability, five showed acceptable reliability, and two were rated as inadequate. The SM demonstrated exceptional test-retest reliability in the sagittal plane while exhibiting marginally worse performance in the frontal plane regarding assessing spinal curvatures, deformation, and mobility.

Ruthard et al. [34] assessed the intra-rater reliability of the SM assessments in children with cerebral palsy (CP) and investigated differences following one week of a rehabilitation program. 168 SM examinations in the sagittal and frontal planes at three measurement intervals from a sample of 28 children with CP were deemed appropriate for evaluation. The findings indicate substantial intra-rater reliability for the SM measurements in both the sagittal and frontal planes (ICC values = 0.69–0.99). SM can be utilized to produce dependable metrics for the functional study of the spine in pediatric patients with CP.

Okanishi et al. [35] analyzed the characteristics of postural alterations in pregnant versus non-pregnant women. The study group comprised fifteen women in the 17–34-week gestational period, while the control group included ten non-pregnant female volunteers. Spinal curvature was assessed using SM to determine the averages of sacral inclination, thoracic curvature, and lumbar curvature and inclination. Eleven pregnant women had postural traits of lumbar kyphosis and sacral posterior inclination. Body inclination exhibited diverse patterns in contrast to those observed in healthy women. Spinal curvature exhibited a propensity for lumbar kyphosis in pregnant women. Pregnancy can induce alterations in spine curvature and posture, potentially resulting in significant problems.

Jung et al. [36] examined the relationship between SM (continuous measurement), Flexicurve, and Arcometer (selected measurement). Ninety healthy subjects were assessed for thoracic kyphosis using non-radiological measuring instruments (SM, Flexicurve, and Arcometer). The association between SM and Flexicurve assessments of thoracic kyphosis was substantial (ICC=0.53, 95% CI=0.37–0.67). The correlation between the SM and Arcometer readings of thoracic kyphosis was substantial (ICC=0.58, 95% CI=0.42–0.70). The average discrepancy between the SM and Arcometer was 12.70 degrees, whereas the difference between the SM and Flexicurve was 23.83. Although Flexicurve and Arcometer correlate strongly with the SM, their agreement is inadequate. Consequently, physical therapists must use caution when interpreting the outcomes.

Demir et al. [21] examined the reliability of the SM device in frontal and sagittal measurements among asymptomatic female teenagers. The survey was comprised of 28 female students from high school institutions in Antalya that were comparable. Measurements were conducted using the SM device in both the frontal and sagittal planes at a one-week interval. This investigation revealed that the test-retest findings for thoracic and lumbar region measurements in the frontal plane exhibited moderate reliability (ICC: 0.591-0.665), while those in the sagittal plane showed strong reliability (ICC: 0.867-0.876). This study revealed that the test-retest findings for thoracic and lumbar area measures in the frontal plane exhibited reasonable reliability. The test-retest outcomes for the thoracic and lumbar curves in the sagittal plane demonstrated strong reliability.

In summary, 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 aims to elucidate the reliability of the SM for assessing the spine in different age groups, as shown by the tests and studies previously described. According to current investigations, this study 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 and kyphosis.

3.Materials and methods

3.1Hardware and software design

The device is constructed using easily accessible and cost-effective components. The circuit components are interconnected to provide the intended functionality of each element. The electrical circuit of the proposed system is shown in the system schematic diagram illustrated in *Figure 1*. The circuit is described in detail, including each component, its function, and the interface with the microcontroller. The software integrates easily into the hardware system, serving as an essential component of the entire system.

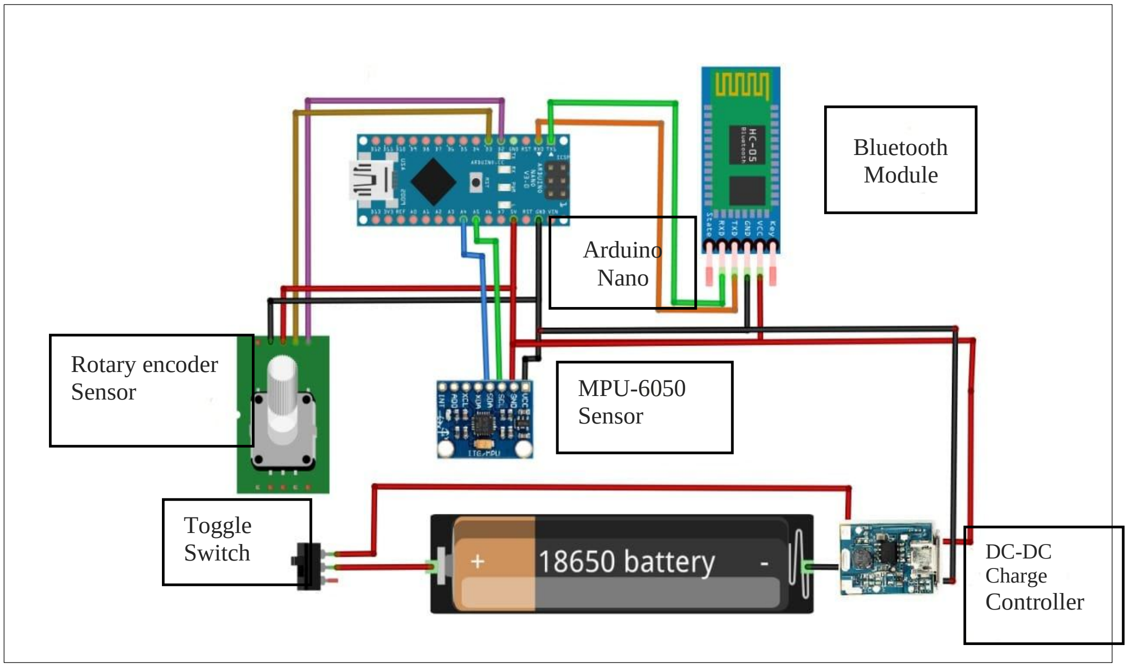


Figure 1 Schematic diagram of the developed system

The Arduino Nano, a microcontroller with dimensions of 45×18 mm, was employed as a compact development board to facilitate seamless integration with other device components [37]. This integration aimed to minimise the device's dimensions, enhancing portability. The angle between the two vertebrae and the angle of the thoracic segment and the lumbar segment were measured using a 3-axis Gyroscope sensor, namely the GY-521 MPU6050 model. The sensor detects the inclination of the X, Y, and Z axes. It has dimensions of 4×4×0.9 mm [38]. The MPU6050 can be calibrated by designing a base, on which the device is placed after each examination so that the Gyroscope value is zeroed due to its horizontal orientation. Prior to any investigation, the sensor axes within the device are set to zero.

The rotary encoder, model E38, Incremental type, was used to measure the displacement of the device on the spine. It has an outside diameter of 38 mm and a shaft diameter of 6 mm. This particular encoder was chosen for calculating linear displacement due to its cost-effectiveness, low maintenance needs, exceptional resistance to noise [39].

To calibrate the encoder and calculate the distance, a mark was affixed to the wheel with a diameter of 60 mm. The wheel was then traversed over a ruler and advanced by 800 pulses, signifying a full rotation. The encoder traversed a distance of 23 cm, then converted to millimetres. The value of 230 mm was divided by 800 pulses, yielding a ratio of 0.2875. The quantity of pulses produced during the encoder's revolution on the patient's back is multiplied by 0.2875 and thereafter translated to millimetres. As a result, the distance has been quantified in millimetres rather than pulses [40].

The suggested device used a Bluetooth module, the HC-06 model, to facilitate wireless data transmission to the computer. The HC-06 is the optimal selection for wireless communications within short distances. It was employed for wireless communications within a range of under 100 m. This specific type of Bluetooth technology is readily accessible in the market at an affordable price. Furthermore, it can transmit data at a maximum rate of 2.1 MB/s [41]. Bluetooth and Wi-Fi both use the 2.4 GHz frequency band. On the other hand, the 2.4 GHz band is free of signal interference while using Bluetooth, in contrast to Wi-Fi [42].

The proposed device used a rechargeable lithium-ion battery, namely the 18650 model, with a voltage range of 3.6 to 3.7 volts. The battery was activated by toggling the switch to the "on" position. This battery is lightweight, easily storable, has good energy density, and experiences minimal energy loss during periods of inactivity, with an efficiency of up to 99.9 per cent [43]. The 18650 battery has a life cycle of around 300 charge cycles [44].

Nevertheless, the Arduino Nano microprocessor functions at a voltage of 5V [45]. Consequently, a DC-DC charge controller, measuring 27×17×1 mm, has been incorporated into this system to regulate the voltage. The charger has an input voltage range of 4.5 V to 5.5 V and has been designed for charging single-cell lithium-ion batteries. It offers both constant-current and constant-voltage charging [46].

Furthermore, two input buttons are integrated into the proposed device, each connected to pins D6 and D7 of the Arduino Nano microcontroller. The top button is used to capture the position and angle of the current vertebra, while the bottom button restores the angle of the previously recorded vertebra. These buttons enhance examiner comfort during the assessment, as the device only records data when the examiner has identified the correct position. The process involves the examiner pressing the top button to log the reading, moving the device to the next vertebra, and repeating the action—thus enabling a vertebra-by-vertebra measurement of the spine.

Furthermore, these buttons minimise discrepancies in error rates among examiners when the duration of button pressing varies. Specifically, the reading of the pertinent vertebra is just recorded and does not transition to the next vertebra until the examiner removes their hand from the button. The bottom button is positioned to make it easier to adjust the reading in case the examiner makes a mistake in selecting a vertebra.

For the software component of the proposed system, Visual Studio was utilized, with Visual Basic as the programming language. The mechanical designs of the system were created using SolidWorks software (version 2022), as illustrated in *Figure 2*. These designs were subsequently fabricated using a 3D printer based on fused deposition modelling (FDM) technology, employing polylactic acid (PLA) as the printing material. PLA is a biodegradable polymer derived from renewable resources such as corn, sugarcane, wheat, and rice. It is both eco-friendly and non-toxic. Additionally, its lightweight properties help reduce the overall weight of the device, enhancing portability and ease of use for the examiner. PLA filament has gained widespread popularity in the field of 3D printing, particularly for FDM applications [47].

The dimensions of the device structure, including the wheel, are as follows: height = 8 cm, width = 8 cm, length = 13 cm, and wheel diameter = 60 mm, as illustrated in *Figure 3*. The base of the device has dimensions of height = 4 cm, width = 10 cm, and length = 20 cm, also shown in *Figure 3*.

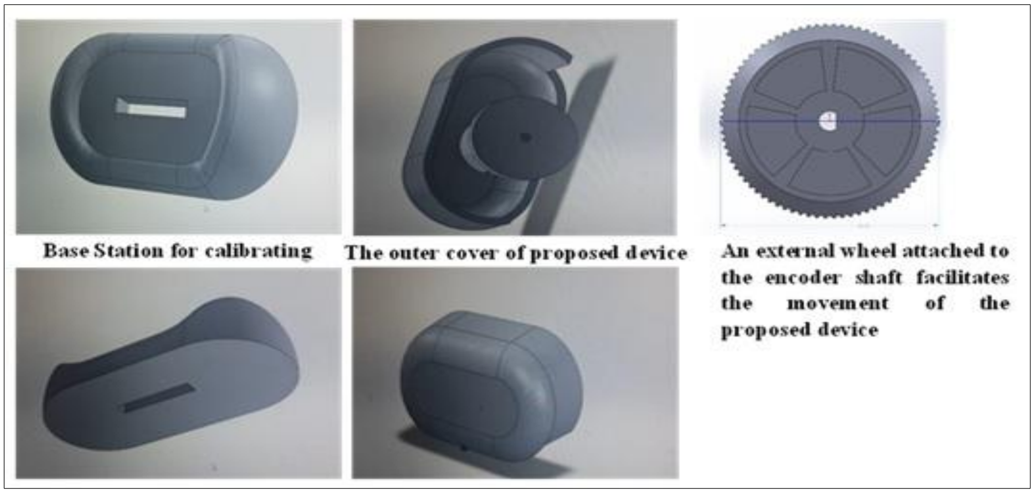


Figure 2 Design using the SolidWorks program

Figure 3 The developed device with the base

3.2Measured parameters

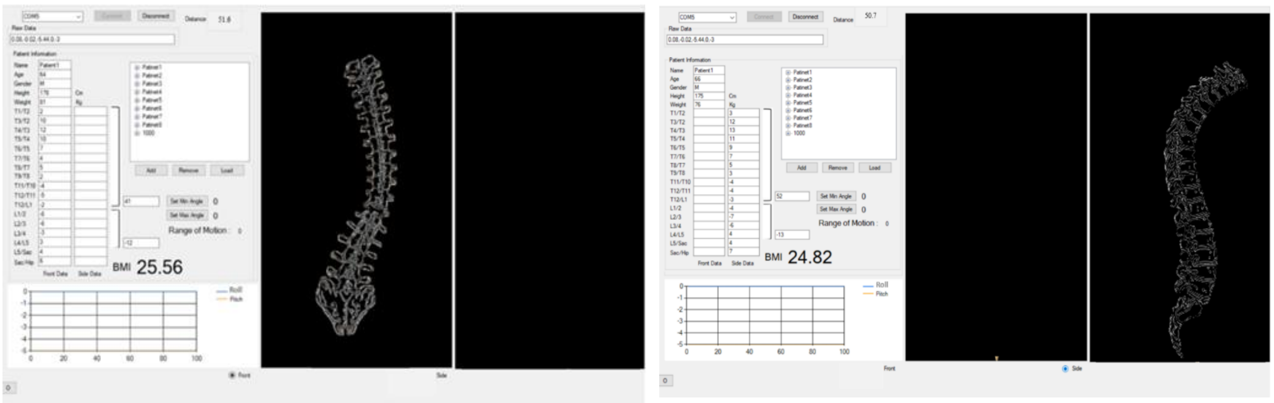
The parameters that were measured are as follows:

- 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) (kyphotic angles are expressed as positive values, lordotic angles as negative values).
- The L5/sacral spine angle.
- The sacral spine/hip angle in both the frontal plane (left lateral flexion and right lateral flexion positions) and the sagittal plane (flexion and extension positions).

The back's length and spin mobility, which are equivalent to a ROM, have been measured. Two dynamic signals have been incorporated to improve the examiner's visual perception during the examination and to validate the correct execution of the assessment. One signal indicates the pitch angle for calculating the frontal plane, while the other suggests the roll angle for calculating the sagittal plane, *Figure 4* displays the software program's user interface (UI).

3.3Study population

This study included 20 patients aged over 55 years. The first group consisted of 10 women diagnosed with DS, and the second group had ten men diagnosed with kyphosis. All patients had a Cobb angle ≥ 20˚. These patients were selected based on the inclusion criteria at outpatient clinic from March 2024 to July 2024. The healthcare provider collected the patient's medical history and noted their demographic information, as shown in *Table 1*, followed by a thorough examination and x-ray for patients diagnosed with DS and kyphosis. The study was conducted after obtaining ethical approval and permission from the Al-Nahrain University Internal Review Board. Every patient has read and agreed to the informed consent form. The exclusion criteria for this trial encompassed congenital anomalies such as hemivertebra, prior spinal surgery, skin folds or scars that might limit the approach's application, and curvature deformities not associated with DS or kyphosis. Participants with a history of neuromuscular, cardiovascular, pulmonary, vestibular, or rheumatological diseases were also excluded, as shown in *Figure 5*.



(a) (b)

Figure 4 Analysis of measurement findings obtained with the developed SM and subsequently transferred to the computer, (a) front view, and (b) side view

Table 1 Demographic characteristics of the 20 participants

Variables	DS Group $(\boldsymbol{n=10})^a$	KYPHOSIS Group $(\boldsymbol{n=10})^a$
Age (years)	60.51 ± 2.44	62.34 ± 3.62
Body height (cm)	156.50 ± 4.14	176.70 ± 4.42
Body weight (kg)	59.30 ± 4.32	81.00 ± 3.49
Body mass index (BMI) (kg/$\boldsymbol{m^2}$)	24.25 ± 2.16	25.93 ± 0.75

$a = Mean \pm standard\ deviation.$

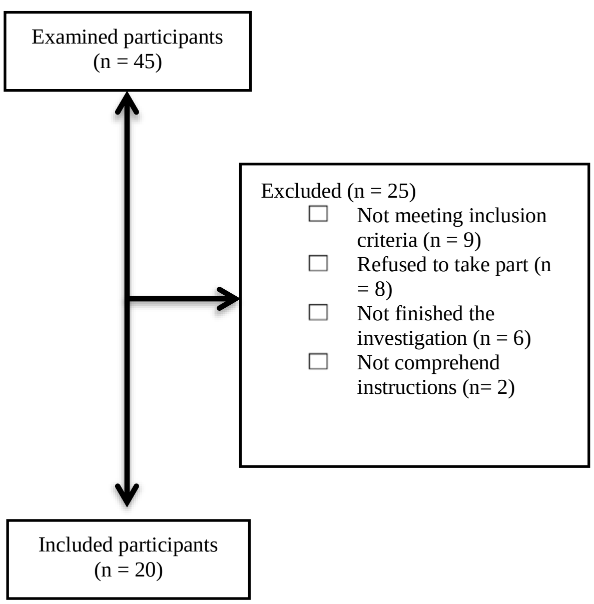
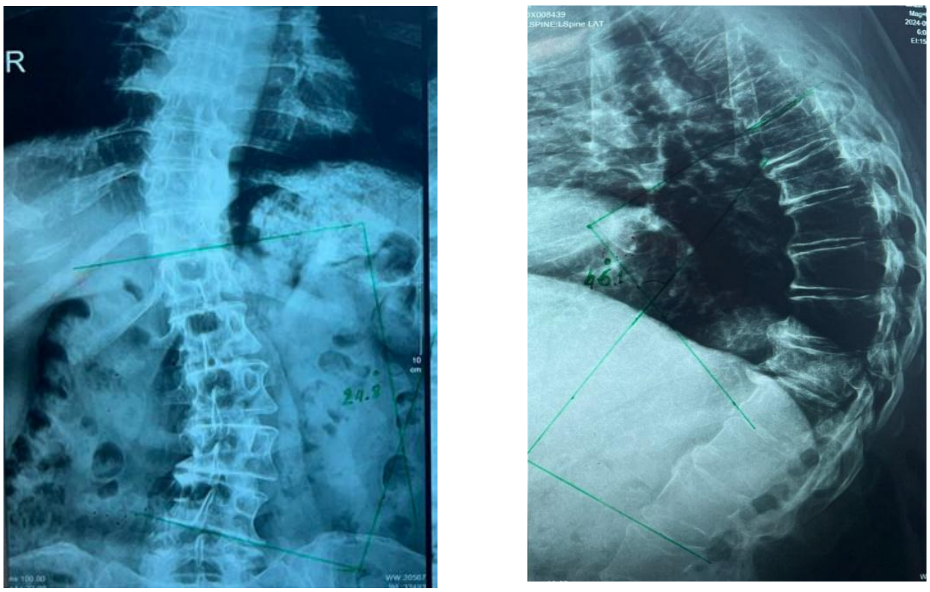


Figure 5 Flowchart illustrating the process of selecting samples and the criteria used for selection

3.4Radiological measurements

The traditional Cobb angle evaluation method identifies the upper and lower-end vertebrae (UEV/LEV) on a full-spine anteroposterior X-ray picture. Afterwards, vertical lines are placed at the corresponding endplate lines of the upper and lower end vertebrae (UEVEL/LEVEL). The Cobb angle refers to the angle formed between these two vertical lines [48]. Frontal plane X-rays were collected from C1 to the coccyx. The X-ray indicated the location of the cranial and caudal vertebrae. Subsequently, a line was delineated from the endplate of each spine to quantify the maximum angle [49], as shown in *Figure 6(A)*. X-ray images of the patients' spines were obtained using a Shimadzu Mobile X-Ray System (MUX-100H, Japan). After centring the X-ray kyphotic angle at T8, a modified Cobb technique was used with a fixed cutoff of T4 and T12 (*Figure 6(B)*). The modified Cobb method uses a predetermined cutoff of T4 and T12 because T1-T3 are not visible on lateral spine films [50, 51] as much as the original Cobb method, which used inflexion angles to determine the upper and lower bounds for line positioning [52]. When it was not possible to see vertebrae 4 and 12, the next closest visible one was used as a stand-in; this was usually vertebra T5 in the case of T4 and vertebra T11 in the case of T12.

Two orthopedic specialists assessed the Cobb angle on radiographs, which showed anteroposterior scoliosis and lateral kyphosis. The printed radiographs were positioned on a lightbox, and the primary angle was determined by precise measurements using a pen, ruler, and protractor [53]. Because the film measurements for the X-ray machine are 17×17, it is difficult to photograph the whole length of the spine, including the vertebrae of the thoracic and lumbar regions. To resolve this issue, it is necessary to capture a photograph of each segment, which entails the acquisition of two images for each plane to measure the Cobb angle for each section individually. However, this approach results in many readings, necessitating more effort and time to categorise and organise them. Following that, the developed SM assessment findings were contrasted among their own, as well as the Cobb angle evaluations performed by the first observer (Cobb 1), considered the "gold standard" and conducted by a doctor with years of clinical results, to evaluate the accuracy and consistency of the developed SM.



(a) (b)

Figure 6 (a) AP radiograph of a patient with Cobb angle of scoliosis. (b) Lateral radiograph of a patient with Cobb angle of kyphosis

3.5SM measurement

The proposed device transmits data to the computer using Bluetooth, and the computer display shows the measured curvatures. The approach is safe and poses no medical risks or dangers. The device is equipped with a rolling wheel that follows the spinous process, allowing for easy movement of the developed SM along the spine. It is also connected to a rotary encoder to determine the distance of the spine and an MPU6050 sensor that detects inclination. Transmission of data from the device to a personal computer allows for the computation of spinal angles, distances between vertebrae, and the sum of the angles formed by the frontal and sagittal planes. Additionally, the program is employed to determine the ROM. The collected data is transferred immediately to a PC, producing a 2-D graphical spine picture. The PC used to gather information was roughly 1.5 meters from the registration place. During the data transmission via Bluetooth, no additional radios or cell phones were present in the measuring room to avoid the risk of interfering. Two investigators with differing degrees of clinical skill performed the developed SM measures to improve the assessment of the effects of experiences. The first physiotherapist had six years of clinical experience, whereas the succeeding one had three years of clinical experience. The measures were conducted in a calm and adequately illuminated setting, devoid of distractions for both the participant and the examiner. The participants were told to adopt a symmetrical stance, equally dispersing their weight across both feet to the maximum extent feasible. Consistent methodology was employed for all measurements conducted in a standardised sequence. Initially, the processus spinosus of the C7 was identified through manual examination and marked using a cosmetic pen. Subsequently, the initial physiotherapist positioned a marker from the C7 to S1 vertebrae while the patient maintained an upright stance in the anatomical position. The developed SM was then elevated along the spinal landmarks as the device moved from the stationary segment of the spine (proximal) to the mobile segment (distal).

Following the initial assessment by the first examiner, the second examiner assessed the patient in an identical posture. Each physiotherapist conducted two repetitions of measures for each patient, resulting in four measurements per patient. The mean for each examiner was then taken. The sagittal plane for assessing patients with kyphosis is demonstrated when the subject stands upright with feet in line and approximately shoulder-width wide. The hands must be aligned in an anatomy-correct position parallel to the trunk. b) The participant was instructed to achieve maximum body flexion while standing, with their knees completely straight, and lower their hands in a parallel manner as if trying to touch their toes. They were directed to maintain this position temporarily. c) The examiner was instructed to fully extend their legs and execute a complete backward torso extension while keeping their head upright and sustaining this posture, as shown in *Figure 7*.

Frontal plane to measure the patients with DS: a) In the upright position, the subject was asked to put their hands parallel to the body in an anatomical posture, keep their head straight, and position their feet parallel and shoulder-width apart. b) During left lateral flexion, the participant was instructed to incline their torso to the left while maintaining a uniform weight balance on both feet. c) Each participant received instructions for uniform weight distribution on both feet while laterally bending their body to the right.

In the sagittal plane, there are two curvatures of the spine: the thoracic curvature, which includes the vertebrae T1-T12, and the lumbar curvature, which includes the vertebrae L1-L5. The examiner evaluated these attributes in all positions, including extension (Ext) and full flexion (Flex). Furthermore, the device's software was employed to assess spinal mobility and the aforementioned attributes for the subsequent movements: The ROM encompasses transitioning from an upright posture to full flexion (UF), from an upright stance to full extension (UE), and from full flexion to full extension (FE).

In the frontal plane, the spine exhibits two types of curvatures: the thoracic curvature, encompassing the vertebrae T1-T12, and the lumbar curvature, comprising the vertebrae L1-L5. Both the left and right lateral flexions were analysed by the examiner in every position. In addition, the device software was used to determine the mobility of the spine and the parameters above for the following movements: The movements include transitioning from an upright stance to complete leftward flexion (UL), transitioning from an upright stance to complete rightward flexion (UR), and transitioning from complete leftward flexion to complete rightward flexion (LR). The measurements were conducted in the morning to mitigate potential patient position variations caused by weariness, stress, psychological issues, and other related circumstances.

(a) (b) (c) (d)

Figure 7 Evaluation of the spine in the sagittal plane with the developed SM, a) patient's kyphosis, in b) upright, c) flexion, and d) extension positions

3.6Analysis of statistics

Descriptive statistical statistics, such as the mean ± SD, were represented using the patients' demographic information and measurement findings. The statistical studies were conducted using the IBM SPSS 21 software package. The reliability of measuring the length and angle of the back in the sagittal and frontal planes and the ROM was evaluated using the inter-rater reliability analysis. This analysis used ICC and 95% confidence intervals (CI). The inter-rater reliability, specifically the ICC (2, k) 2-way-random with an average measure (k = 2 examiners), quantifies the variation between two or more examiners when evaluating the same group of individuals.

Generally, a higher ICC value indicates more excellent reliability, ranging from 0 to 1. A number below 0.40 for the ICC was categorised as poor, while a value between 0.40 and 0.59 was regarded as fair. A value between 0.60 and 0.74 was classified as good, and a value between 0.75 and 1.00 was considered excellent [54].

Descriptive statistics, such as the mean ± SD, were used to represent the patients' demographic information and measurement findings. Statistical analyses were performed using the IBM SPSS Statistics software package, version 21. The reliability of measuring spinal length and angle in the sagittal and frontal planes, as well as the ROM, was evaluated using inter-rater reliability analysis. This analysis employed the ICC along with 95% CI. Specifically, the ICC (2, k) model—a two-way random-effects model with average measures (k = 2 examiners)—was used to quantify the agreement between two examiners assessing the same group of individuals. In general, higher ICC values indicate greater reliability, with values ranging from 0 to 1. ICC values were interpreted as follows [54]:

- Below 0.40: **Poor**
- Between 0.40 and 0.59: **Fair**
- Between 0.60 and 0.74: **Good**
- Between 0.75 and 1.00: **Excellent**

4.Results

The study population comprised two cohorts of individuals: 10 men with kyphosis (mean kyphosis angle = 53°, SD = 20.74°) and 10 women with DS. Among those with DS, 30% had bilateral curvature deformity, while 70% had unilateral curvature deformity. The deformity was located on the left side in 60% (6 out of 10) of cases and on the right side in 40% (4 out of 10) of cases. In the kyphosis group, the average age was 62.34, with SD of 3.62. The average age in the DS group was 60.51, with SD of 2.44 (*Table 1*).

4.1Sagittal plane

Patients who had kyphosis performed measurements in the sagittal plane while in upright, flexion, and extension positions, and their ROM was also assessed. All sagittal plane metrics showed no notable variance among initial and later assessments for the kyphosis group. All the parameters have a demonstrated high level of reliability, ranging from 0.783 to 0.985, as shown in *Table 2*. *Figure 8* presents a box plot comparing the 1st rater and 2nd rater in the sagittal plane.

Table 2 The variables of spinal function and motion in the sagittal plane among kyphotic individuals (n=10), as measured by the developed SM

Variables	1st Examine (A Degree)	2nd Examine (A Degree)	ICC [95% CI]
Up Thor	51. .839 ± 11.362	51. 007 ± 11.407	0.946 [0.905–0.970]
Up Lumbar	-34. 839 ± 10.067	-36.775 ± 12.981	0.867 [0.725–0.936]
Flex Thor	70.478 ± 12.542	69.581 ± 11.416	0.897 [0.811–0.941]
Flex Lumbar	12.763 ± 18.754	12.000 ± 19.852	0.982 [0.964–0.990]
Ext Thor	45.189 ± 15.800	44.645 ± 16.104	0.959 [0.925–0.975]
Ext Lumbar	-38.600 ± 16.000	-39.871 ± 18.438	0.783 [0.549–0.895]
UF Incl	80.902 ± 17.893	79. 516 ± 20.840	0.975 [0.958–0.983]
UE Incl	-13.450 ± 10.840	-13.710 ± 9.107	0.966 [0.924–0.988]
FE Incl	97.670 ± 8.070	96.129 ± 11.864	0.985 [0.965–0.992]

The first and second examinations are provided as mean ± SD. ICC stands for the intra-class correlation coefficient. CI stands for confidence interval, Inclination Angle= Incl

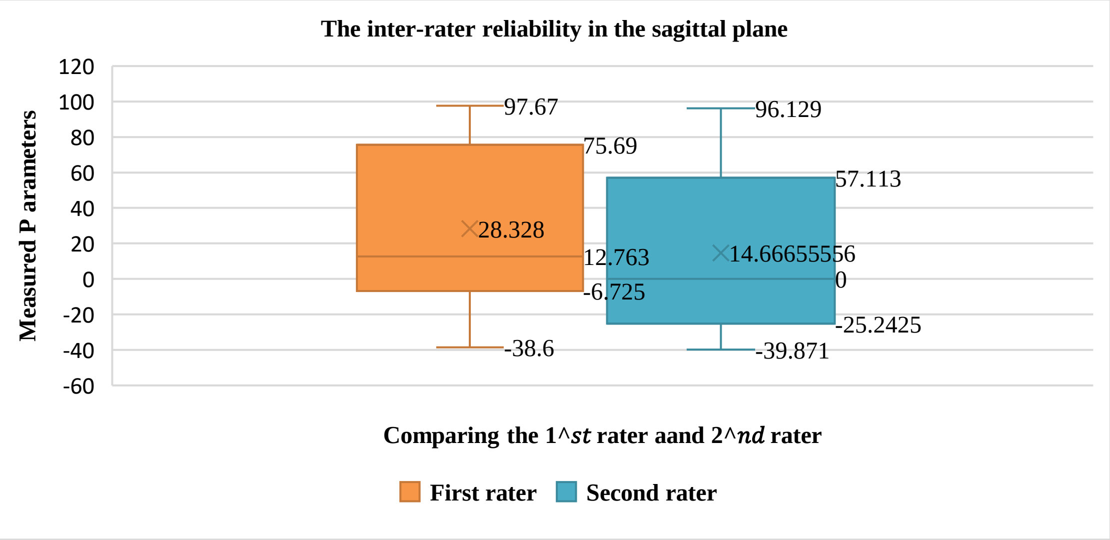


Figure 8 A box plot comparing the 1st rater and 2nd rater of the inter-rater reliability in the sagittal plane

4.2Frontal plane

Patients with DS were assessed in the frontal plane while upright and during right and left lateral flexion positions, and their ROM was evaluated. Except for the variables right and left lumbar, there were no significant differences in the measurements for practically all parameters in *Table 3*. The ICC calculation demonstrated reduced reliability compared to sagittal plane measurements in *Table 2*. All the parameters have a demonstrated high level of reliability, ranging from 0.791 to 0.933, as shown in *Table 3*. *Figure 9* presents a box plot comparing the 1st rater and 2nd rater in the frontal plane.

Table 3 The variables of spinal function and motion in the frontal plane among participants with DS (n=10) are assessed using the developed SM

Variables	1ST Examine (A Degree)	2ND Examine (A Degree)	ICC [95% CI]
Upright Thor	17.452 ± 5.999	16.255 ± 6.184	0.879 [0.749–0.942]
Upright Lumbar	25.545 ± 5.569	23.903 ± 4.096	0.807 [0.703–0.931]
Left Thor	74.095 ± 4.990	72.993 ± 3.732	0.827 [0.703–0.910]
Left Lumbar	20.980 ± 12.800	17.971 ± 10.109	0.791 [0.683–0.880]
Right Thor	-29.672 ± 6.230	-27. 916 ± 5. 752	0.927 [0.943–0.951]
Right Lumbar	-13.942 ± 4.890	-8.900 ± 2.105	0.804 [0.593–0.905]
UL Incl	-32.004 ± 13.910	-30.974 ± 12.301	0.894 [0.785–0.933]
UR Incl	9.943 ± 13.436	9.210 ± 13.582	0.912 [0.799–0.943]
LR Incl	24.673 ± 21.831	23. .503 ± 20.982	0.933 [0.861–0.968]

DS denotes degenerative scoliosis. The first and second examinations are provided as mean ± SD. ICC stands for the intra-class correlation coefficient. CI stands for confidence interval, Inclination Angle= Incl

4.3Cobb angle

The thoracic angle (Upright Thoracic) of patients diagnosed with kyphosis in the upright position in the sagittal plane, as shown in *Table 2*, was measured by two examiners and compared to the Cobb angle obtained from lateral thoracic X-ray images assessed by two orthopedists. Similarly, the same two examiners evaluated the lumbar angle (Upright Lumbar) of patients with DS in the upright position in the frontal plane, as presented in *Table 3*. This comparison was made against the Cobb angle determined by two orthopedists using anterior-posterior thoracic X-rays, due to the higher prevalence of lumbar deformities among the patients.

The mean Cobb angle measured by the first orthopedist (Cobb 1), considered the standard reference, was 55.086 ± 20.742 for kyphosis and 26.545 ± 15.569 for DS, as shown in *Table 4.*

The examination time using the developed device was shorter than that required for X-ray assessment. Spinal alignment evaluation via X-ray involves multiple steps: obtaining the image, followed by manual Cobb angle measurement by an orthopedic specialist. In contrast, the developed SM device enables faster assessment, requiring only a skilled physiotherapist to identify the vertebral landmarks. The device then automatically calculates the vertebral angles, streamlining the measurement process.

Analysis of multiple measurements revealed a little discrepancy in the Cobb-angle readings recorded by two orthopedics from identical radiography. Nonetheless, different raters detected no variance in the SM measures. No disparity was observed between the Cobb-one estimation and the developed SM readings obtained by the two investigators. In addition, a high level of agreement was observed between examiners for both the developed SM and Cobb angle measurements. The ICC ranged from 0.860 to 0.924 for kyphosis and from 0.833 to 0.889 for DS, indicating good reliability, as presented in *Table 5*. *Figure 10* illustrates a Bland–Altman plot that compares the agreement between the Cobb angle and the measurements obtained using the developed SM. *Figure 11* presents a scatter plot comparing the Cobb angle and the developed SM measurements for patients with kyphosis and scoliosis. The plot demonstrates a strong positive correlation between the two methods, with data points closely following the line of best fit. This further confirms the concurrent validity of the developed SM against the radiographic gold standard.

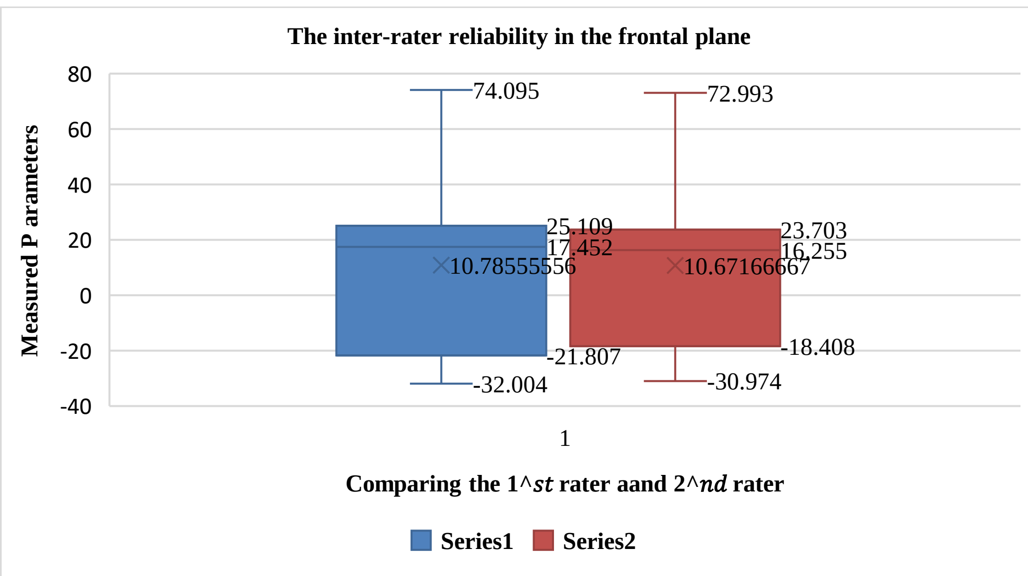
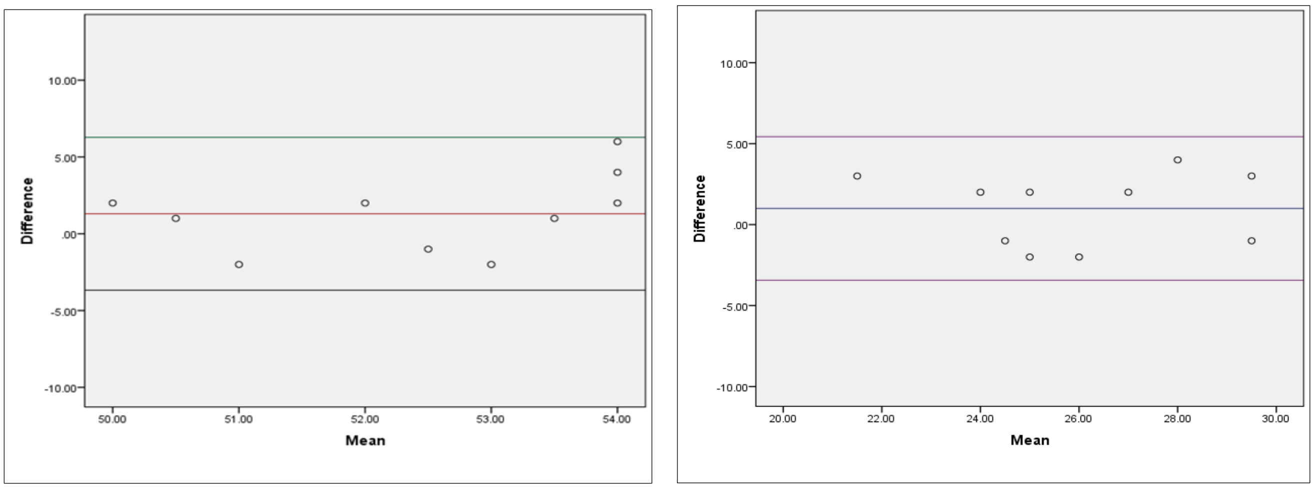


Figure 9 A boxplot comparing the 1st rater and 2nd rater of the inter-rater reliability in the frontal plane

Table 4 Distribution, comparison, and agreement of the developed SM and Cobb measurements

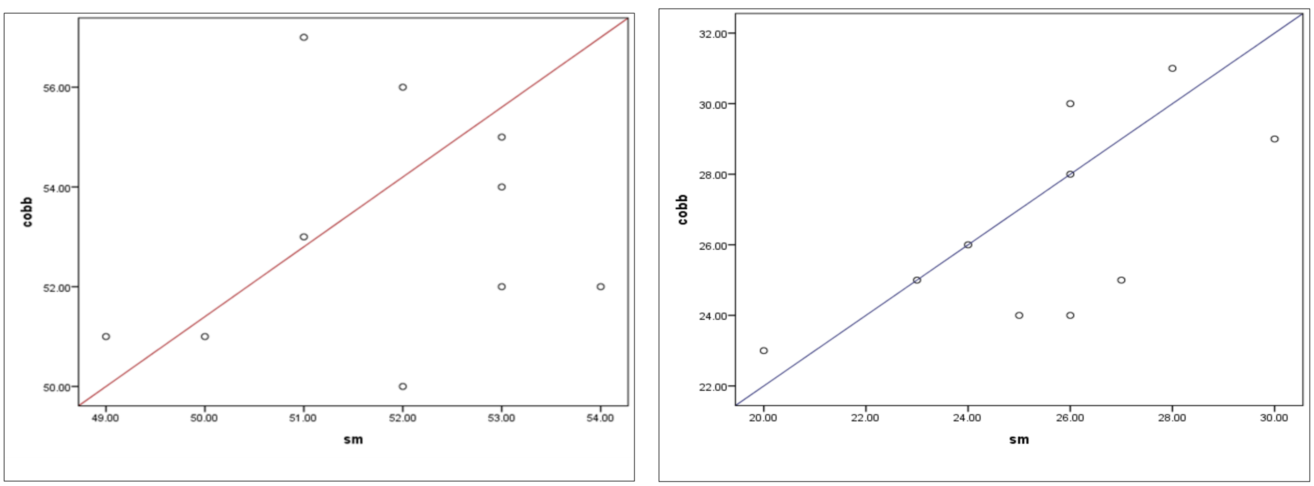
Parameter			**MEAN ± SD**	**ICC [95% CI]**
Interrater Cobb	**Kyphosis**	1st observer	53.086 ± 20.742	0.912 [0.834–0.979]
		2nd observer	55.908 ± 17.619	
	DS	1st observer	26.545 ± 15.569	0.802 [0.705–0.927]
		2nd observer	29.903 ± 14.096	
Interrater the developed SM	**Kyphosis**	1st observer	51. .839 ± 13.362	0.946 [0.905–0.970]
		2nd observer	51. 007 ± 12.407	
	DS	1st observer	25.545 ± 12.569	0.807 [0.703–0.931]
		2nd observer	23.903 ± 9.096	

DS denotes degenerative scoliosis. The first and second evaluations are provided as mean ± SD. ICC stands for the intra-class correlation coefficient. CI stands for confidence interval



(a) (b)

Figure 10 A Bland-Altman plot between Cobb angle and the developed SM agreement for (a) kyphosis, and (b) DS



(a) (b)

Figure 11 Scatter plot comparing the developed SM measurements with Cobb angle values for (a) kyphosis and (b) DS

Table 5 The agreement of assessment outcomes

Approaches		**ICC [95% CI]**
Cobb 1–SM 1	Kyphosis	0.924 [0.872–0.962]
	DS	0.889 [0.804-0.935]
Cobb 1–SM 2	Kyphosis	0.860 [0.764–0.918]
	DS	0.833 [0.723-0.897]

5.Discussion

This study evaluated the reliability of the developed SM device in detecting spinal curvature and mobility for assessing scoliosis in patients with degenerative conditions, as well as in individuals with kyphosis. The findings suggested that the developed SM approach is both valid and reliable.

Upon reviewing the literature, it is evident that radiographic examination is the most widely acknowledged approach for diagnosing scoliosis and kyphosis and tracking their development. The Cobb angle measurement is the most accurate way to evaluate the degree of curvature, which is considered the gold standard [48, 55].

Researchers have devised multiple techniques and instruments to safeguard patients from the adverse consequences of x-rays [15]. Additionally, the need to reduce radiation exposure for the general community and patients has spurred the advancement of alternative assessment methods. Some devices for measuring spinal curvature include the scoliometer, flexible curve ruler, debrunner kyphometer, photographer gadget, raster stereography, and 3D ultrasound. Many such methods fail to examine the spine as a cohesive entity. In contrast, they selectively capture a segment, usually concentrating on the thoracic or lumbar spine. Simultaneously, they yield outcomes solely within a single dimension [56]. The current study on the developed SM focuses mainly on assessing the inter-rater reliability for evaluating spinal curvature and movement, particularly in the sagittal and frontal planes. The study also compared the outcomes of these evaluations with the Cobb angle measurement.

At 0.75, outstanding reliability can be distinguished from fair-to-good reliability, while at 0.4, fair-to-good reliability can be distinguished from lousy reliability [57]; this assessment indicates that the developed SM would offer much enhanced and nearly exceptional reliability. More precisely, the evaluation in the sagittal plane demonstrated excellent reliability. For patients diagnosed with kyphosis, the interrater ICCs ranged from 0.783 to 0.985.

The ICCs were calculated to be 0.783; this ICC value indicates that the measurement of the curvature of the lower back in a fully extended position referred to as Ext Lumbar, showed good reliability. Compared to earlier research, one possible reason for the lower reliability values of Ext Lumbar measurements could be the frequent cases where the developed SM did not keep complete contact with the patient's back. Although the motion assessment was carried out with great precision in these instances, the irregular contact of the device with the patient's spine may have led to measurement mistakes that could have affected the stated reliabilities. In a separate study, the developed SM's inter-rater reliability was assessed in healthy individuals and those with chronic spinal fractures but no neurological deficits. The study focused on inclination, flexion, and extension measurements in the sagittal plane. The results indicated that the ICC ranged from 0.92 to 0.95 [24]. Furthermore, the ICCs from complete flexion to complete extension were determined to be 0.76 during the measurements [24]. The present research analysed the factors influencing the spine's ROM in the sagittal plane, from complete flexion to complete extension (FE Incl.). The findings indicated that the ICCs for this ROM were 0.985, with a range of 0.965 to 0.992.

The evaluation of the created SM in the frontal plane demonstrated slightly lower validity compared to the sagittal plane. For DS patients, the interrater ICCs ranged from 0.791 to 0.933. The ICCs demonstrated 0.791, 0.804, and 0.807 in the left lateral, right lateral, and upright lumbar positions, respectively, likely due to the incomplete contact between the developed SM and the patient's lumbar region.

The existing method is an effective instrument for assessing deformities of the side spinal curves, particularly scoliosis, in the frontal plane. A potential explanation for the higher global interrater reliability observed in this study compared to previous reports is that every examiner can use identical skin marks for their evaluations. Mannion et al. [25] discovered that employing identical skin markings for mobility evaluations yielded more reliability than utilising skin markings independently applied by each tester. In addition, the study [24] used a potentiometer to assess the angle and tilt of the spine. However, the accuracy of this sensor's measurements depends on the examiner's grip on the device. Moreover, since the sensor calculates the angle relative to the vertical, the results may vary when multiple examiners handle the device and pass it over the patient's back. This study addressed the issue by using an MPU6050 gyroscope sensor to measure the angle between the vertebrae. This method eliminates reliance on the examiner’s grip and removes the need for examiner intervention.

This investigation showed a notable disparity in the Cobb measurements conducted by different examiners. However, no variation was observed in the interrater results for the developed SM. The developed SM outcomes did not differ considerably from the Cobb 1 results. The association between the developed SM and Cobb measures and the interrater developed SM results for sagittal and frontal planes was exceptionally strong. The association between x-ray data and the developed SM has demonstrated that the developed SM is reliable for measuring scoliosis and kyphosis. Multiple investigators have assessed potential variations in Cobb angle measurements. The mean values indicate that the variation in Cobb measurements among individuals is comparable to that in the developed SM measurements from Cobb values. One unique feature is that the developed SM readings from different examiners have fewer difference angles than any other discrepancy angle, which shows that the developed SM is reliable. Over time, patients with scoliosis experience deformities in their vertebrae. The enlarged discs on the concave side undergo atrophy, whilst the developing discs on the convex side undergo hypertrophy. As time passes, the spinous structures undergo deformation and eventually move towards the concave side of the curve [58]. The developed SM gadget uses the palpable spinous structures as reference points. Errors are minimised by employing this method. A complete list of abbreviations is listed in *Appendix I*.

Limitations

One limitation of this study is the use of a single rater to consistently mark the spinous processes for motion assessment, which was intended to control for confounding variables. While this approach enhanced the internal accuracy of the results, it limited the ability to evaluate inter-observer variability—an important consideration for clinical reproducibility, as patients would need to be re-evaluated by different clinicians during follow-up assessments. Additionally, all evaluations were conducted on the same day, which restricts the generalizability of the reliability findings. The consistency of spinal mobility measurements using the developed SM device over multiple days remains unverified. Another critical factor influencing measurement accuracy with the developed SM device is the precise identification of the spinous processes and the smooth, consistent movement of the device over these anatomical landmarks. The accuracy of vertebral labeling and measurement reliability may be affected by the subject's BMI and the amount of overlying soft tissue. Further limitations include potential discrepancies in readings during extension measurements when subjects experienced discomfort or imbalance due to repeated testing. Moreover, during forward flexion, the expansion of skin markings caused contact between adjacent vertebral marks, resulting in occasional misreadings. Environmental factors, such as temperature and humidity, also influence the performance of the developed SM device. To mitigate this, all measurements were carried out in a controlled environment.

Overall, to minimize human error and ensure reliable outcomes, spinal assessments using the developed SM should be performed with a high level of concentration, precision, and examiner expertise.

6.Conclusion and future work

The findings of this study indicate that the developed SM device demonstrates exceptionally high interrater reliability in assessing spinal curvature in both the sagittal and frontal planes, as well as spinal mobility in individuals with kyphosis and DS. While radiographic evaluation remains the gold standard for clinical decision-making, particularly in cases requiring surgical intervention, the developed SM proves to be a valuable tool for follow-up assessments.

The device was designed to facilitate the tracking of spinal curvature in studies involving the progression of various spinal disorders and the effectiveness of corresponding treatments. Its use significantly reduces the need for repeated radiographic imaging, thereby minimizing patient exposure to radiation during routine follow-up visits. In this context, the developed SM appears to be a suitable method for non-invasive spinal evaluation by healthcare professionals, including physiotherapists. This study contributes to the development of evaluation tools for diagnosing and monitoring patients with DS and kyphosis and represents the first investigation to validate this approach specifically in this patient population.

Below are some recommendations which may be taken into account for future work:

1. Additional research with a more significant number of participants is proposed.
2. Research may also be conducted to examine the influence of deformity type, namely in the sagittal plane (kyphosis) or the frontal plane (scoliosis), on gender, whether male or female.

Acknowledgment

None.

Conflicts of interest

The authors have no conflicts of interest to declare.

Data availability

None.

Author's contribution statement

Israa Khalifa Mahan: Responsible for conceptualising and designing the work, interpreting and analysing data, and writing and revising the original manuscript. **Aseel Ghazwan:** Responsible for conceptualising and developing the work and interpreting and analysing it. **Luay Asaad Mahmood:** Responsible for conceptualising and designing the project, executing the execution, and interpreting and analysing the results.

References

[1] Bazira PJ. Clinically applied anatomy of the vertebral column. Surgery (Oxford). 2021; 39(6):315-23.

[2] Rutherford BR, Taylor WD, Brown PJ, Sneed JR, Roose SP. Biological aging and the future of geriatric psychiatry. Journals of Gerontology Series A: Biomedical Sciences and Medical Sciences. 2017; 72(3):343-52.

[3] Picavet HS, Hazes JM. Prevalence of self reported musculoskeletal diseases is high. Annals of the Rheumatic Diseases. 2003; 62(7):644-50.

[4] Roghani T, Zavieh MK, Manshadi FD, King N, Katzman W. Age-related hyperkyphosis: update of its potential causes and clinical impacts-narrative review. Aging Clinical and Experimental Research. 2017; 29:567-77.

[5] Spitzer S, Shaikh M. Health misperception and healthcare utilisation among older Europeans. The Journal of the Economics of Ageing. 2022; 22:1-11.

[6] Amaral AS, Simões MR, Freitas S, Vilar M, Sousa LB, Afonso RM. Healthcare decision-making capacity in old age: a qualitative study. Frontiers in Psychology. 2022; 13:1-14.

[7] Jandrić S. Scoliosis and sport. Sport Logia. 2015; 11(1):1-10.

[8] Dimitrakis N, Zafeiris CP. Neuromuscular scoliosis: a narrative review. Journal of Research & Practice on the Musculoskeletal System. 2023; 7(2):38-43.

[9] Kim H, Lee CK, Yeom JS, Lee JH, Cho JH, Shin SI, et al. Asymmetry of the cross-sectional area of paravertebral and psoas muscle in patients with degenerative scoliosis. European Spine Journal. 2013; 22:1332-8.

[10] Corona-cedillo R, Saavedra-navarrete MT, Espinoza-garcia JJ, Mendoza-aguilar AN, Ternovoy SK, Roldan-valadez E. Imaging assessment of the postoperative spine: an updated pictorial review of selected complications. BioMed Research International. 2021; 2021(1):1-20.

[11] Nakipoglu GF, Karagoz A, Ozgirgin N. The biomechanics of the lumbosacral region in acute and chronic low back pain patients. Pain Physician. 2008; 11(4):505-11.

[12] Machida M, Rocos B, Zabjek K, Lebel DE. A comparison of the reliability and vulnerability of 3D sterEOS and 2D EOS when measuring the sagittal spinal alignment of patients with adolescent idiopathic scoliosis. Spine Deformity. 2022; 10(5):1029-34.

[13] Gori T, Münzel T. Biological effects of low-dose radiation: of harm and hormesis. European Heart Journal. 2012; 33(3):292-5.

[14] Brenner DJ, Elliston CD. Estimated radiation risks potentially associated with full-body CT screening. Radiology. 2004; 232(3):735-8.

[15] Oakley PA, Ehsani NN, Harrison DE. The scoliosis quandary: are radiation exposures from repeated X-rays harmful? Dose-Response. 2019; 17(2):1-10.

[16] Barrett E, Mccreesh K, Lewis J. Reliability and validity of non-radiographic methods of thoracic kyphosis measurement: a systematic review. Manual Therapy. 2014; 19(1):10-7.

[17] Todd CM, Agnvall C, Kovac P, Sward A, Johansoon C, Sward L, et al. Validation of spinal sagittal alignment with plain radiographs and the debrunner kyphometer. Medical Research Archives. 2015; 2(1):1-25.

[18] Roggio F, Petrigna L, Trovato B, Zanghì M, Sortino M, Vitale E, et al. Thermography and rasterstereography as a combined infrared method to assess the posture of healthy individuals. Scientific Reports. 2023; 13(1):1-10.

[19] Cohen L, Kobayashi S, Simic M, Dennis S, Refshauge K, Pappas E. Non-radiographic methods of measuring global sagittal balance: a systematic review. Scoliosis and Spinal Disorders. 2017; 12:1-2.

[20] Colati R, Pagano SA, Colati SR, Pagano A. Effectiveness of osteopathic treatment on the spinal column as measured by the spinal mouse®: a case series. Cureus. 2022; 14(8):1-9.

[21] Demir E, Güzel N, Çobanoğlu G, Kafa N. The reliability of measurements with the spinal mouse device in frontal and sagittal planes in asymptomatic female adolescents. Annals of Clinical and Analytical Medicine. 2020; 11(2):146-9.

[22] Domokos B, Beer L, Reuther S, Raschka C, Spang C. Immediate effects of isolated lumbar extension resistance exercise (ILEX) on spine posture and mobility measured with the IDIAG spinal mouse system. Journal of Functional Morphology and Kinesiology. 2023; 8(2):1-10.

[23] Roghani T, Zavieh MK, Rahimi A, Talebian S, Manshadi FD, Baghban AA, et al. The reliability of standing sagittal measurements of spinal curvature and range of motion in older women with and without hyperkyphosis using a skin-surface device. Journal of Manipulative and Physiological Therapeutics. 2017; 40(9):685-91.

[24] Post RB, Leferink VJ. Spinal mobility: sagittal range of motion measured with the SpinalMouse, a new non-invasive device. Archives of Orthopaedic and Trauma Surgery. 2004; 124:187-92.

[25] Mannion AF, Knecht K, Balaban G, Dvorak J, Grob D. A new skin-surface device for measuring the curvature and global and segmental ranges of motion of the spine: reliability of measurements and comparison with data reviewed from the literature. European Spine Journal. 2004; 13:122-36.

[26] Kellis E, Adamou G, Tzilios G, Emmanouilidou M. Reliability of spinal range of motion in healthy boys using a skin-surface device. Journal of Manipulative and Physiological Therapeutics. 2008; 31(8):570-6.

[27] Zafereo J, Wang-price S, Brown J, Carson E. Reliability and comparison of spinal end-range motion assessment using a skin-surface device in participants with and without low back pain. Journal of Manipulative and Physiological Therapeutics. 2016; 39(6):434-42.

[28] Livanelioglu A, Kaya F, Nabiyev V, Demirkiran G, Fırat T. The validity and reliability of “spinal mouse”

assessment of spinal curvatures in the frontal plane in pediatric adolescent idiopathic thoraco-lumbar curves. European Spine Journal. 2016; 25:476-82.
[29] Walaa SM, Walaa ME. Prevalence of scoliosis among Majmaah university physical therapy students-Saudi Arabia. International Journal of Medical Research & Health Sciences. 2018; 5(10):187-91.
[30] Azevedo N, Ribeiro JC, Machado L. Balance and posture in children and adolescents: a cross-sectional study. Sensors. 2022; 22(13):1-14.
[31] Azevedo N, Ribeiro JC, Machado L. Back pain in children and adolescents: a cross-sectional study. European Spine Journal. 2023; 32(9):3280-9.
[32] Popova-ramova E, Poposka A, Ramov L. School screening for spine deformity with clinical test and spine mouse device. Jokull Journal. 2013; 63(7):97-105.
[33] Topalidou A, Tzagarakis G, Souvatzis X, Kontakis G, Katonis P. Evaluation of the reliability of a new non-invasive method for assessing the functionality and mobility of the spine. Acta of Bioengineering and Biomechanics. 2014; 16(1):117-24.
[34] Ruthard K, Raabe-oetker A, Ruthard J, Oppermann T, Duran I, Schönau E. Reliability of a radiation-free, noninvasive and computer-assisted assessment of the spine in children with cerebral palsy. European Spine Journal. 2020; 29:937-42.
[35] Okanishi N, Kito N, Akiyama M, Yamamoto M. Spinal curvature and characteristics of postural change in pregnant women. Acta Obstetricia Et Gynecologica Scandinavica. 2012; 91(7):856-61.
[36] Jung SH, Hwang UJ, Kim JH, Ha SM, Kwon OY. Correlation among non-radiological measurements for thoracic kyphosis. Journal of Musculoskeletal Science and Technology. 2020; 4(1):1-5.
[37] https://www.sigmaelectronica.net/wp-content/uploads/2016/06/A000005.pdf. Accessed 19 April 2025.
[38] https://invensense.tdk.com/wp-content/uploads/2015/02/MPU-6000-Datasheet1.pdf. Accessed 19 April 2025.
[39] Arslan A. Comparative analysis of speed decoding algorithms for rotary incremental encoders. Master's Thesis, School of Electrical Engineering, Aalto University. 2022.
[40] Khalifa I, Ghazwan A, Mahmood LA. The assessment of spinal alignment based on a computer-assisted electromechanical device. Al-Nahrain Journal for Engineering Sciences. 2024; 27(4):477-85.
[41] https://www.rajguruelectronics.com/Product/707/HC-06%20core%20bluetooth%20module.pdf. Accessed 19 April 2025.
[42] Tshiluna NB, Mathevula HL, Rimer S, Pinifolo J, Paul BS, Jayram S, et al. Analysis of bluetooth and wi-fi interference in smart home. In international conference on advances in computing and communication engineering 2016 (pp. 13-8). IEEE.
[43] Onah CI, Mbamara US, Ebegbulem MM. Design, construction and testing of a solar charged multi-USB power bank using lithium-ion batteries. Journal of Instrumentation Technology & Innovation. 2016; 6(1):61-76.
[44] https://www.ineltro.ch/media/downloads/SAAItem/45/45958/2b4fb0d5-bfc7-4a45-8c2f-592265c6810f.pdf. Accessed 19 April 2025.
[45] https://docs.arduino.cc/hardware/nano/. Accessed 19 April 2025.
[46] https://www.handsontec.com/dataspecs/module/18650-Lithium%20charger.pdf. Accessed 19 April 2025.
[47] Baran EH, Erbil HY. Surface modification of 3D printed PLA objects by fused deposition modeling: a review. Colloids and Interfaces. 2019; 3(2):1-25.
[48] Wang J, Zhang J, Xu R, Chen TG, Zhou KS, Zhang HH. Measurement of scoliosis cobb angle by end vertebra tilt angle method. Journal of Orthopaedic Surgery and Research. 2018; 13:1-7.
[49] Gstoettner M, Sekyra K, Walochnik N, Winter P, Wachter R, Bach CM. Inter-and intraobserver reliability assessment of the cobb angle: manual versus digital measurement tools. European Spine Journal. 2007; 16:1587-92.
[50] Goh S, Price RI, Leedman PJ, Singer KP. The relative influence of vertebral body and intervertebral disc shape on thoracic kyphosis. Clinical Biomechanics. 1999; 14(7):439-48.
[51] Singer K, Jones TJ, Breidahl PD. A comparison of radiographic and computer-assisted measurements of thoracic and thoracolumbar sagittal curvature. Skeletal Radiology. 1990; 19:21-6.
[52] Harrison DE, Cailliet R, Harrison DD, Janik TJ, Holland B. Reliability of centroid, cobb, and harrison posterior tangent methods: which to choose for analysis of thoracic kyphosis. Spine. 2001; 26(11): e227-34.
[53] Morrissy RT, Goldsmith GS, Hall EC, Kehl D, Cowie GH. Measurement of the cobb angle on radiographs of patients who have scoliosis. Evaluation of Intrinsic Error. JBJS. 1990; 72(3):320-7.
[54] Koo TK, Li MY. A guideline of selecting and reporting intraclass correlation coefficients for reliability research. Journal of Chiropractic Medicine. 2016; 15(2):155-63.
[55] Woods GN, Huang MH, Lee JH, Cawthon PM, Fink HA, Schousboe JT, et al. Factors associated with kyphosis and kyphosis progression in older men: the MrOS study. Journal of Bone and Mineral Research. 2020; 35(11):2193-8.
[56] Vaz G, Roussouly P, Berthonnaud E, Dimnet J. Sagittal morphology and equilibrium of pelvis and spine. European Spine Journal. 2002; 11:80-7.
[57] Fleiss JL. Design and analysis of clinical experiments. John Wiley & Sons; 2011.
[58] Parent S, Labelle H, Skalli W, Latimer B, De GJ. Morphometric analysis of anatomic scoliotic specimens. Spine. 2002; 27(21):2305-11.

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Appendix I

S. No.	Abbreviation	Description
1	AIS	Adolescent Idiopathic Scoliosis
2	BMI	Body Mass Index
3	CI	Confidence Interval
4	CP	Cerebral Palsy
5	DS	Degenerative Scoliosis
6	FE Incl.	Fluxion to Extension Inclination Angle
7	FDM	Fused Deposition Modelling
8	ICC	Intraclass Correlation Coefficient
9	LBP	Low Back Pain
10	LR	Leftward Flexion to Rightward Flexion
11	PLA	Polylactic Acid
12	ROM	Range of Motion
13	SD	Standard Deviation
14	SEM	Standard Errors of Measurement
15	SM	Spinal-Mouse
16	UE	Upright Stance to Full Extension
17	UEV/LEV	Upper and Lower-End Vertebrae
18	UF	Upright to Fluxion
19	UL	Upright to Leftward Fluxion
20	UR	Upright to Rightward Fluxion
21	2D	Two Dimensional
22	3D	Three Dimensional