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Original Article

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Reliability and Validity of Angle of Trunk Rotation Measurement Using Smartphone and 3D Printing Technology in Scoliosis

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Purpose: The purpose of this study was to compare and analyze the method of measuring the angle of the trunk rotation using a smartphone with 3D smartphone holder compared to a scoliometer, which is a measuring tool used as a method for diagnosing scoliosis in scoliosis patients.

Methods: Angle of trunk rotation was measured in 21 subjects diagnosed with scoliosis. scoliometer measurement method, a smartphone measurement method with a 3D smartphone holder, a smartphone blind measurement method with a 3D smartphone holder, a smartphone measurement method without a smartphone holder, a smartphone blind measurement method without a smartphone holder, and a total of five measurement methods were repeated three times for comparison and analysis.

Results: The smartphone measurement method with a 3D smartphone holder has excellent intra-rater reliability of angle of trunk rotation (Rater A; ICC3, $2 \geq 0.993$, Rater B; ICC3, $2 \geq 0.992$). The smartphone blind measurement method with a 3D smartphone holder has excellent inter-rater reliability of angle of trunk rotation (ICC2, $2 \geq 0.968$). The scoliometer measurement method had the highest validity ($r = 0.976$) with the smartphone measurement method with a 3D smartphone holder, and the blind measurement method without a smartphone holder had the lowest validity ($r = 0.886$).

Conclusion: These findings, the angle of trunk rotation measured by the smartphone measurement method with a 3D smartphone holder in scoliosis patients showed high reliability and validity compared to the scoliometer measurement method.

Keywords: Scoliosis, Scoliometer, 3D printing, Smartphone holder

INTRODUCTION

Scoliosis is an asymmetric deformation of the rib cage that results in the deformation of the organs that can lead to functional problems. These problems can impair the lung function in normal breathing and cause serious dysfunction depending on the degree of progression.[1-3] The asymmetry is observed in the external appearance of the body because of the asymmetry of the spine. In adolescence, a period when considerable attention is paid to appearance, it can cause psychological atrophy that can affect social life.[4-6] Eighty percent of adolescent scoliosis is idiopathic scoliosis, the cause of which is unclear, and no particular pain appears. The prevalence of growth in adolescents under 16 years of age is 2–3%, and the risk increases as the child ages because the deformity proceeds until bone growth is complete. Early detection and therapeutic intervention through medical examinations are necessary to slow the progression of the spinal deformity and correct the deformity.[7-10]

The Cobb's angle, which measures the displaced vertebral angle of the coronal plane in scoliosis, is the most important measurement method.[11] Although a radiographic examination is required to measure the Cobb's angle, it is difficult to detect the early onset, and a radiographic examination, which is used to confirm the effectiveness of therapeutic interventions in the treatment process, has several negative problems due to frequent exposure to radiation.[12-14] Scoliosis can be examined by measuring the angle of trunk rotation using a scoliometer devised by Bunnell in

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1984. The scoliometer is portable, easy to inspect, has proven reliability, and does not need to be exposed to radiation, but it is expensive and inaccessible.[15-17]

Smartphones with many sensors, such as accelerometers and gyroscopes, are excellent mechanical devices that can be used instead of existing measurement equipment. The average penetration rate is 76% in 18 advanced countries, so it can be easily accessed.[18-20] The spread of smartphones has led to studies to replace existing measurement equipment using built-in mechanical devices and platform applications. It is used in relation to health in most well-being fields.[21] In the production of products, the current 3D printing technology has made significant progress by reducing manufacturing costs and improving printing speed and precision and is being used in various fields, such as medical equipment, implant materials, and cell printing.[22] In the future, 3D printing technology will be used in more fields based on high precision, and experts predict that customized production will exceed 50%.[23]

Various studies have been conducted and verified in the medical field using smartphones and 3D printing technology. On the other hand, there have been few studies on measurement methods using smartphones and 3D printing technology in scoliosis patients. Based on previous studies on the precision of smartphones and 3D printing technology, it was assumed that the method of using a smartphone and a product made from 3D printing technology would be as reliable as using a scoliometer.

Accordingly, this study intends to present the rationale so that the method using a smartphone and 3D printing technology can be used instead of the method using the existing scoliometer. Therefore, this study examined the reliability and validity of an angle of trunk rotation measurement using a smartphone and a 3D smartphone holder in scoliosis.

METHODS

1. Subjects

This study was conducted with adolescents and adults between the ages of 10 and 40 living in P city, Korea, who were diagnosed with scoliosis by their doctor. 24 participants participated in the study, but 3 dropped out in the course of the study, and 21 (male: 5, female: 16) subjects were the final subjects.

Subjects included both those who were currently receiving treatment for scoliosis and those who were not. The study focused only on measuring the angle of trunk rotation and did not take any other measures. The criteria for selection of study subjects are as follows. 1) Those who do not have a difference of 2 cm or more in leg length, 2) Those who have not undergone scoliosis surgery or other lower extremity surgery, 3) Those who do not have pain or disease that may affect the measurement during the anterior flexion test.

Subjects obtained approval from the Bioethics Committee of Daegu University (1040621-202011-HR-009) for patients who fully understood the purpose and process of the study and gave voluntary consent before conducting the study.

2. Study protocol

In this study, five measurement methods were used to verify the reliability and validity of the method of measuring the angle of trunk rotation of scoliosis patients using a smartphone and a 3D smartphone stand made with 3D printing technology.

First, for patients with scoliosis, a landmark for measuring the angle of trunk rotation was marked on the protruding area during the forward bending test using a scoliometer. In the landmarked area with scoliometer measurement method, a smartphone measurement method with a 3D smartphone holder, a smartphone blind measurement method with a 3D smartphone holder, a smartphone measurement method without a smartphone holder, a smartphone blind measurement method without a smartphone holder, a total of 5 measurement methods, were repeated 3 times each in the same order. Two raters measured 15 times for each measurement method, and a total of 30 repeated measurements were given to the subject, and a rest period was given between the measurement methods. Measurements were made continuously without a time interval between the raters, and all measurements were completed in one day. If pain or discomfort in the lower back or legs occurred, the measurement was stopped and the measurement was restarted at the time of revisit.

3. Measurement tools

1) Scoliometer

In 1984, Bunnell's scoliometer, a measuring tool first devised to measure the angle of trunk rotation of scoliosis patients, is sold online. Among them, the scoliometer used in the experiment is the most sold and used product, and the size is 170×65×12 mm.

2) Smartphone

The smartphone is a Galaxy S10 (SM-G973N, SAMSUNG Electronics Co., Ltd., Korea) made by Samsung Electronics and was released in February 2019. It uses the Android operating system and measures 149.9×

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70.4×7.8 mm and weighs 158 g. The smartphone's built-in sensors include accelerometer, proximity sensor, ambient light sensor, compass, gyro, heart rate sensor, RGB light sensor, hall sensor, Sp02, and fingerprint sensor.

3) 3D smartphone holder

A computer-aided design (CAD) program was used to create a product with a computer. It was made by imitation of the shape of the scoliometer and designed to be able to mount the smartphone Galaxy S10 model. The size is 170×40×45 mm. As a CAD (computer-aided design) program, Autodesk's Tinkercad was used, and the STL file was commissioned and produced by a 3D printing company. The 3D printer is a Fortus 450 mc model from stratasys, and this product uses the FDM method that melts the plastic material with heat and sprays it with a nozzle to stack the layers (Figure 1).

4) Bubble Level application

To measure the angle of trunk rotation of scoliosis a smartphone, a level (Bubble Level (Bubble Level, NixGame, Russian Federation)) with good visibility and a large number of downloads from Google playstore among applications using the accelerometer built into the smartphone was used. This tool uses an accelerometer (g-force) and is designed to measure angles (horizontal and vertical), tilt, balance, length and height (ruler) and display them on the screen.

5) Forward bending test tool

It was used for repeated measurements in the same posture during the forward bending test to measure the angle of trunk rotation of scoliosis patients. The footrest is a pedalo product, and lines are drawn at regular intervals to the left and right based on the center line so that the patient can maintain the same width of the foot in a standing position. Using two yoga blocks, the position of the patient's hand was marked with a sticker at the position where the angle of trunk rotation was measured during the forward bending test so that the body could be forward bended to the same height during the repeated forward bending test.

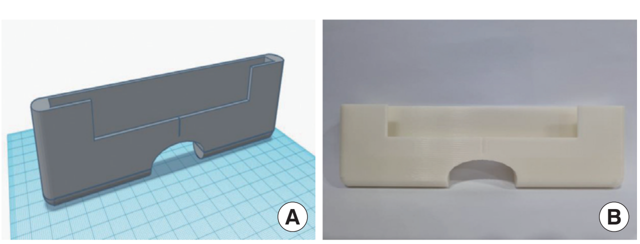

Figure 1. 3D smartphone holder. (A) 3D smartphone holder designed with Tinkercad. (B) 3D smartphone holder made with a 3D printer.

4. Study method

1) Measurement method of tools

(1) Scoliometer measurement method

Before measuring the angle of trunk rotation of scoliosis patient, in order to set the reference point of the scoliometer, the scoliometer was placed on the floor and focused. In the forward bending test, the angle of trunk rotation was measured using a scoliometer on the area to be measured marked with a sticker. The measured value was read and recorded by the rater who measured it (Figure 2A).

(2) Smartphone measurement method with a 3D smartphone holder

After running Bubble Level, the application used for measurement, the part to be measured marked with a sticker was measured in the forward bending test by mounting the smartphone on a 3D smartphone holder. The measured value was read and recorded by the rater who measured it (Figure 2B).

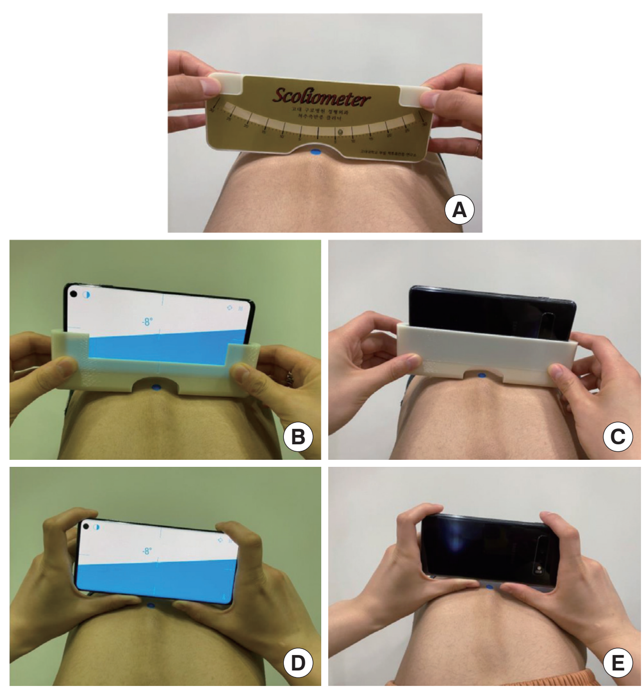

Figure 2. Measurement method of tools. (A) scoliometer measurement method. (B) smartphone measurement method with 3D smartphone holder. (C) smartphone blind measurement method with 3D smartphone holder. (D) smartphone measurement method without a smartphone holder. (E) smartphone blind measurement method without a smartphone holder.

(3) Smartphone blind measurement method with a 3D smartphone holder

After running Bubble Level, the application used for measurement, it was mounted on the 3D smartphone holder, and the 3D smartphone holder was turned in the opposite direction to prevent the rater from seeing the measured values. In the forward bending test, the area to be measured marked with a sticker was measured. Measurements were read and recorded by another rater standing on the opposite side (Figure 2C).

(4) Smartphone measurement method without a smartphone holder

The lower part of the smartphone is placed on the thumb, and the upper part is fixed with the index finger to make it similar to a scoliometer. After running Bubble Level, the application used for measurement, put the hand holding the smartphone on the floor and practiced to focus. In the forward bending test, the area to be measured marked with a sticker was measured. The measured value was read and recorded by the rater who measured it (Figure 2D).

(5) Smartphone blind measurement method without a smartphone holder

The smartphone holder was reversed to prevent the rater from seeing the measurements. In the forward bending test, the area to be measured marked with a sticker was measured. The measured value was read and recorded by the rater who measured it (Figure 2E).

2) Measurement method of angle of trunk rotation

In forward bending test conducted to measure the angle of trunk rotation of scoliosis patients, the rater first instructed the subject to 'forward bend' while standing comfortably with their legs outstretched so that they bent their upper body forward as much as possible. Then, he instructed him to 'get up' and made his upper body stand up slowly. He instructed to 'stop' at the part with the greatest difference in height. The same posture was maintained for 2 seconds, and the rater obtained the displayed measurement value using the measurement methods used to measure the angle of trunk rotation. Measurements were carried out by two physical therapists, one who had experience in treating scoliosis patients and one who had no experience in treating scoliosis patients. After fully understanding the measurement method and practicing, the research was conducted. Rater with experience in treating scoliosis patients first measured the angle of trunk rotation using a scoliometer, and then checked the width of the foot at the first measurement to measure the height in the same posture. The measured back area was marked with a sticker, and the position of the hand was marked with a sticker when another rater performed the forward bending test. After the measurement site was marked, the first rater measured and recorded the measured value, and then the second rater measured the same site repeatedly in the same posture. In the blind measurement method, after the subject took the measurement posture, the measuring device was turned in the opposite direction to prevent the rater from seeing the measured value and the angle of trunk rotation was measured, and the measured value was read and recorded by the rater on the other side.

Scoliometer measurement method, a smartphone measurement method with a 3D smartphone holder, a smartphone blind measurement method with a 3D smartphone holder, a smartphone measurement method without a smartphone holder, a smartphone blind measurement method without a smartphone holder, A total of 5 measurement methods were repeated 3 times each in the same order. One rater measured 15 times, and the subject was repeated a total of 30 times, and a break was given between measurements. In case of pain or discomfort in the lower back or legs, the measurement was stopped and the measurement was restarted from the beginning when revisiting.

5. Statistical analysis

In the analysis of this study, 24 people were tested, but 3 people dropped out due to complaints of discomfort during the experiment, so a total of 21 people were measured. Angle of trunk rotation was measured in a total of 28 places and the data were analyzed. For the data collected for the purpose of the study, the mean and standard deviation were calculated for the measured variables using IBM SPSS statistics 20 (SPSS, Inc, Chicago, IL, USA). Statistical significance was defined at $\alpha = 0.05$. Intraclass correlation coefficient was performed to analyze the reliability of the measured angle of trunk rotation within and between raters, and Pearson correlation coefficient was performed for validity analysis.

RESULTS

1. General characteristics of study subjects

A total of 21 subjects participated in this study, consisting of 5 males and 16 females, with an average age of 22.3 ± 7.2 years, an average height of 163.1 ± 6.7 cm, and an average weight of 55.4 ± 11.8 kg. As for the type of scoliosis, 6 patients had single thoracic curve, 9 patients had single lumbar curve, and 7 patients had double curve. The mean Cobb angle of thoracic

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Table 1. General characteristics of study subjects

Items	Mean±SD
Age (yr)	22.3±7.2
Sex	
Male	5
Fmale	16
Height (cm)	163.1±6.7
Weight (kg)	55.4±11.8
Curve type	
Thoracic	5
Lumbar	9
Double	7
Cobb angle (°)	
Thoracic	16.1±5.5
Lumbar	19.6±7.0

Values are Mean±SD or number.

Table 2. Intra-rater reliability of the measurement method

	Rater A		Rater B	
	$ICC_{(3,2)}$	95%CI	$ICC_{(3,2)}$	95%CI
Scoliometer	0.994*	0.990-0.997	0.993*	0.987-0.997
Holder 3D	0.993*	0.987-0.996	0.992*	0.985-0.996
Holder 3DB	0.986*	0.973-0.993	0.992*	0.986-0.996
Phone	0.983*	0.967-0.991	0.987*	0.976-0.994
Phone B	0.989*	0.980-0.995	0.986*	0.973-0.993

Scoliometer: scoliometer measurement method, Holder 3D: smartphone measurement method with 3D smartphone holder, Holder 3DB: smartphone blind measurement method with 3D smartphone holder, Phone: smartphone measurement method without a smartphone holder, Phone B: smartphone blind measurement method without a smartphone holder. *p<0.05.

curve was 16.06±5.53° and the mean Cobb angle of lumbar curve was 19.58±6.96° (Table 1).

2. Reliability of the measuring tool in the angle of trunk rotation measurement method

The intra-rater reliability according to the A-rater's measurement method was scoliometer measurement method 0.994, smartphone measurement method with 3D smartphone holder 0.993, smartphone blind measurement method with a 3D smartphone holder 0.986, smartphone measurement method without a smartphone holder 0.983, smartphone blind measurement method without a smartphone holder 0.989 showed a high level of reliability ($p<0.05$).

B rater's intra-rater reliability was scoliometer measurement 0.993, smartphone measurement method with a 3D smartphone holder 0.992, smartphone blind measurement method with a 3D smartphone holder 0.992, smartphone measurement method without a smartphone holder 0.987, smartphone measurement method without a smartphone holder 0.986, showed a high level of reliability ($p<0.05$)(Table 2).

The inter-rater reliability according to the measurement method was Scoliometer measurement method 0.971, smartphone measurement method with a 3D smartphone holder 0.943, smartphone blind measurement method with a 3D smartphone holder 0.968, smartphone measurement method without a smartphone holder 0.895, smartphone blind measurement method without a smartphone holder 0.937 ($p<0.05$). Scoliometer measurement method showed the highest level of reliability, and smartphone measurement method without a smartphone holder showed the lowest level of reliability ($p<0.05$)(Table 3).

Table 3. Inter-rater reliability of measurement method

	$ICC_{(2,2)}$	95%CI
Scoliometer	0.971*	0.938-0.987
Holder 3D	0.943*	0.877-0.974
Holder 3DB	0.968*	0.932-0.985
Phone	0.895*	0.774-0.952
Phone B	0.937*	0.863-0.971

Scoliometer: scoliometer measurement method, Holder 3D: smartphone measurement method with 3D smartphone holder, Holder 3DB: smartphone blind measurement method with 3D smartphone holder, Phone: smartphone measurement method without a smartphone holder, Phone B: smartphone blind measurement method without a smartphone holder. *p<0.05.

Table 4. Validity of measuring Tool in angle of trunk rotation measurement method

	Scoliometer	Holder 3D	Holder 3DB	Phone	Phone B
Scoliometer	1				
Holder 3D	0.976*	1			
Holder 3DB	0.971*	0.970*	1		
Phone	0.898*	0.877*	0.911*	1	
Phone B	0.886*	0.848*	0.901*	0.965*	1

Scoliometer: scoliometer measurement method, Holder 3D: smartphone measurement method with 3D smartphone holder, Holder 3DB: smartphone blind measurement method with 3D smartphone holder, Phone: smartphone measurement method without a smartphone holder, Phone B: smartphone blind measurement method without a smartphone holder. *p<0.05.

3. Validity of measuring Tool in angle of trunk rotation measurement method

This study compares the method of using a scoliometer, a commonly used tool in measuring the angle of trunk rotation, and the method of using a smartphone and 3D smartphone holder, a new measurement method. As an operational definition, validity is recognized validity.

The angle of trunk rotation measured by the scoliometer measurement method showed the highest correlation with the angle of trunk rotation measured by the smartphone measurement method with a 3D smartphone holder at 0.976 ($p<0.05$). The angle of trunk rotation measured by the smartphone blind measurement method without a smartphone holder showed the lowest correlation at 0.886 ($p < 0.05$)(Table 4).

DISCUSSION

This study evaluated a new measurement method that anyone can easily use as a diagnostic method for scoliosis. To this end, this study examined whether the angle of trunk rotation measured with a 3D smartphone holder made using the application with an accelerometer built into the smartphone and 3D printing technology was reliable and valid compared with the angle of trunk rotation measured with a scoliometer. As a result, in scoliosis, the angle of trunk rotation measured by a smartphone measurement method with a 3D smartphone holder exhibited a higher level of reliability than the value measured using the smartphone measurement method without a smartphone holder, and the scoliometer measurement method. In comparison, the validity of the smartphone measurement method with a 3D smartphone holder was high. In previous studies,[24-26] the angle of trunk rotation measured using an accelerometer sensor built into a smartphone and a smartphone auxiliary device that can hold a smartphone showed a strong correlation with the angle of trunk rotation measured using a scolometer. This means that the angle of trunk rotation of a scoliosis patient measured using a scoliometer and a smartphone showed a similar measurement value with no significant difference in the measurement value, except that the method of taking the measurement is analog or digital. Through this, the reliability is high even when comparing measurement methods using the digital type smartphone application, which is a new tool to replace the analog type scoliometer, a widely used and highly reliable tool.

In this study, the intra-rater correlation according to the measurement method of the angle of trunk rotation revealed rater A to have the strongest correlation with the scoliometer measurement method with a correlation coefficient of 0.994, and the correlation coefficient of the smartphone measurement method without a smartphone holder showed the lowest correlation of 0.983. For rater B, the correlation coefficient of the scoliometer measurement method was 0.993, indicating the strongest correlation, and the smartphone blind measurement method without a smartphone holder had the lowest correlation coefficient of 0.986. In the intra-rater correlation, the correlation coefficient ranged from 0.994 to 0.983, indicating high intra-rater reliability in the measurement method. The following correlations between the raters according to the method for measuring the angle of trunk rotation were obtained: the correlation coefficient of the scoliometer measurement method was 0.971; the correlation coefficient of the smartphone measurement method with a 3D smartphone holder was 0.943; the correlation coefficient for the smartphone blind measurement method with a 3D smartphone holder was 0.968; the correlation coefficient of the smartphone measurement method without a smartphone holder was 0.895; the correlation coefficient of the smartphone blind measurement method without a smartphone holder was 0.937. These results indicate that the measurement method using the 3D smartphone holder showed higher reliability than the smartphone measurement method without a smartphone holder. In measuring the angle of trunk rotation, the smartphone measurement method with a 3D smartphone holder showed a similar strong correlation to the scoliometer measurement method. On the other hand, the smartphone measurement method without a smartphone holder showed a lower correlation than the smartphone measurement method with a 3D smartphone holder by placing the smartphone on the thumbs of both hands and fixing the smartphone with the index finger.

The angle of trunk rotation was measured at the most protruding part of both sides based on the spinous process of the spine. The scoliometer has a rectangular shape, and a groove is cut in the middle so that the spinous process of the spine does not touch. When measuring using the built-in sensor of a smartphone without an accessory tool, it is difficult to measure the angle of trunk rotation in the same way as the scoliometer because the bottom surface of the smartphone is in a straight shape, unlike the scoliometer. Accordingly, various accessory tools were studied and used in previous studies. In this study, the angle of trunk rotation was also measured using a 3D smartphone holder and a smartphone of a similar shape. When measuring the angle of trunk rotation by holding the smartphone by hand without such a smartphone holder, the smartphone cannot be leveled uniformly, unlike when an accessory tool is used. The 3D smartphone holder, which is positioned between the measurement site and the smartphone in the body of a scoliosis patient, plays an accessory role so that the asymmetrical body angle can be measured with a smartphone in a fixed form. On the other hand, when measuring by placing it on the rater's finger, it may not be level depending on the hand holding the smartphone. In the measurement method, when using the 3D smartphone holder, the same measurement method can be used as when measuring with a scoliometer. Nevertheless, subjective effort is required when measuring using only a smartphone, which affects the measured value, resulting in more errors.

Driscoll et al.[27] used a smartphone holder called Scolioscreen that en-

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abled screening tests for spinal deformities with a smartphone application, Scolioscreen-smartphone combination, and smartphone alone, and the observer of the inclination angle measured with a scoliometer. The inter-rater, intra-rater reliability, and accuracy were compared. The Scolioscreen-smartphone intraclass correlation coefficient was 0.94–0.89; the smartphone alone intraclass correlation coefficient was 0.89–0.75; the scolioscreen-smartphone intraclass correlation coefficient was 0.95–0.89. The reliability and consistency of the measurement method used with the holder were similar to that of a scoliometer. As in this study, when measured using a smartphone alone, the reliability was lowered because of the therapist's intervention. A more subjective effort was required than the measurement method that combined a smartphone with a smartphone holder. When measuring the angle of trunk rotation with a smartphone alone, an error occurred during the measurements because the bottom surface of the scoliometer was in a straight line shape, unlike the one made so that the spinous processes of the vertebrae did not touch. Compared to the scoliometer, the measurement method that combines the smartphone and the smartphone holder was manufactured similarly to the scoliometer. Therefore, the reliability is higher by reducing the therapist's intervention than using the smartphone alone measurement method.

In a study that confirmed the accuracy of 3D printing technology used to manufacture a smartphone holder, a 3D printed mandible model was developed as an STL file and compared using five types of printers. By verifying that all five printing technologies were very accurate, the reliability of the 3D printed products used in various ways was increased.[28] By comparing the accuracy of the products manufactured with various 3D printers, the reliability of the designed product was increased for the product manufactured using the 3D printer. On the other hand, the precision of the 3D printer used to make any product using a 3D printer needs to be verified because there are many types of 3D printers, and the products used range from high-precision and expensive to low-precision products that can be used by the general public. The smartphone measurement method with a 3D smartphone holder made using the built-in sensor, and 3D printing technology of a smartphone whose reliability has been verified was found to be more reliable than the smartphone measurement method without a smartphone holder. Both the smartphone measurement method and the smartphone measurement method without a smartphone holder showed higher reliability in the value measured blindly than the value measured while the rater reads the measurement value. The risk of subjectivity from the intervening rater increases when conducting a clinical study through a measurement tool. Hence, the rater conducted a blinded study. A blind study provided significantly lower and more consistent scores than the open study.[29] A blinded study means that the study subject or study rater is unaware of any intervention in the clinical study so that the study is not affected. Unless intervention or bias is excluded in the study, it is better to give the rater greater confidence in the blinded study at a minimum. On the other hand, just because the reliability of the blinded study is high does not mean that the research value in the general study is low. Therefore, it becomes important to increase the reliability of the research by explaining how an objective study was conducted during the research process.[30]

In this study, the angle of trunk rotation of scoliosis patients was measured using a smartphone measurement method with a 3D smartphone holder and a smartphone measurement method without a smartphone holder. A blinded study was conducted together to exclude the subjectivity or bias of the rater. The smartphone blind measurement method with a 3D smartphone holder showed the strongest correlation among the raters, and the correlation with the rater's scoliometer measurement method also showed a strong correlation in the smartphone blind measurement method with a 3D smartphone holder. In a blinded study, the rater directly measured and showed higher reliability and validity than reading the measured value. This is because when the rater reads the measured value directly, it cannot be objective compared to the blinded study, regardless of how well the bias is excluded. Considering the strong correlation of measurement methods in the blinded study, which can be said to be objective and consistent, the smartphone measurement method with a 3D smartphone holder is considered to have high reliability and validity compared to the scoliometer measurement method. Another factor influencing the measurement of the angle of trunk rotation is that the intra-rater reliability is higher than the inter-rater reliability in the case of the scoliometer. One suggestion is that one rater measures the same part in the same posture to increase reliability.[31] When measuring the angle of trunk rotation using a smartphone and an application instead of a scoliometer, the type varies depending on the smartphone manufacturer. Hence, the sensors built into the smartphone may differ, and the types of applications are also diverse, which can result in some errors. Therefore, when measuring the angle of trunk rotation with a smartphone application using a 3D smartphone holder in clinical practice, one rater repeatedly measures the angle of trunk rotation of a scoliosis patient using a single smartphone and application like a scoliometer.[32]

In this study, as a method for measuring the angle of trunk rotation of scoliosis, the smartphone measurement method with a 3D smartphone holder and the smartphone measurement method without a smartphone holder were compared with the scoliometer measurement method. The reliability and validity of the angle of trunk rotation measured using a smartphone and a smartphone holder made with a 3D printer were checked. Using 3D printing technology to produce a smartphone holder, the 3D smartphone holder and a free application along with the precision built-in sensor of the smartphone that can be accessed easily around the world could measure the angle of trunk rotation of scoliosis in a new way. The angle of trunk rotation measured by the smartphone measurement method with the 3D smartphone holder showed higher reliability than the smartphone measurement method without the smartphone holder. Compared to the scoliometer measurement method, the smartphone measurement method with a 3D smartphone holder showed a high level of reliability and validity.

Through this, if the clinic uses a smartphone measurement method with a 3D smartphone holder, a measurement similar to that of measuring the angle of trunk rotation of a scoliosis patient using the scoliometer measurement method can be obtained, which is simpler and more convenient than a scoliometer. This tool is expected to be a new low-cost measurement method. Using this measurement method, scoliosis can be diagnosed quickly in early adolescence, and the severity of scoliosis can be prevented through faster therapeutic interventions during growth.

This study had some limitations due to the small number of test subjects. In addition, changes in the subject's measurement posture may have occurred during the measurement process. Compared to reading the reference value of the smartphone application at 1°, the scoliometer reads the reference value at 0.5°, and there may be a difference in the data value. Further study will be needed to confirm the error of the built-in sensor of the smartphone used for measurement and the reliability of the application used. Therefore, these points should be fully considered when measuring the angle of trunk rotation of scoliosis using a smartphone and a 3D smartphone holder in clinical practice.

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