A Comparative Study of the Sagittal and Coronal Balance of the Spine Measured Using a 3D Full Body Scanner and Spine X-Ray

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1. Introduction

With the aging of the population, adult spinal deformity (ASD) caused by degenerative changes in the spine, is becoming increasingly common. Accurate measurement of spinal balance is required for the diagnosis and treatment of ASD. [1] Currently, the analysis is mainly conducted using X-rays, but there are limitations such as radiation exposure and difficulty in reflecting actual daily postures. On the other hand, radiation free 3D scanning method for the body surface developed with technological advances.[2] The purpose of this study is to compare the efficacy of 3D body scanner analysis and conventional x-ray analysis in measuring ASD.

2. Material and methods

2.1. Device information

This 3D full body scanner is the MediAvatar from the corporation, Medi Help Line, South Korea. This device was composed of multi-connected (3) RealSense D415 Depth Camera Module of Intel.

2.2. Study design

This study is a prospective observational study. The 3D full body scanner uses only infrared rays with no harms. Participants fully understood this study concept. The institutional review board (IRB) at the Seoul National University Boramae Medical Center (SMG-SNU BRM medical center) approved the study protocols after obtaining informed consent (IRB No. 30-2022-68). This study was conducted in compliance with the Declaration of Helsinki.

2.3. Inclusion criteria

This study involved 97 patients who completed clinical questionnaires and underwent 3D body scanning and whole spine X-ray. The participants were the patients who came to our outpatient clinic. All the patients have some their own back discomfort more or less. We included only participants who have no difficulty in standing alone because the base of the scanner rotates slowly for checking full body surfaces.

2.4. 3D scanner measurement

Participants wore the fitted pants and tops we gave. To keep their privacy, privacy screens were used for image acquisition in whole time. We ordered them to stand naturally and grip the adjustable handles besides the base for preventing the fall down. But we ordered not to lean their upper body on the handle using their both arms. The 3D scanning device utilizes Infrared ray to image the body surface, and automatically recognizes coordinates by measuring the inflection points. In the sagittal plane analysis, points A(ear), B(shoulder), C(hip), and D(knee) were recognized automatically and labelled. We created 3 concepts to analyze the correlation between the points. First one is the angle of two points with respect to the plumb line (ex. aAB_sag). Second one is the horizontal distance between two points (ex. dAB_hor). Third one is the angle of three points (ex. angle of ABC). In the coronal plane analysis, the shoulder gradients were measured. (Figure 1)

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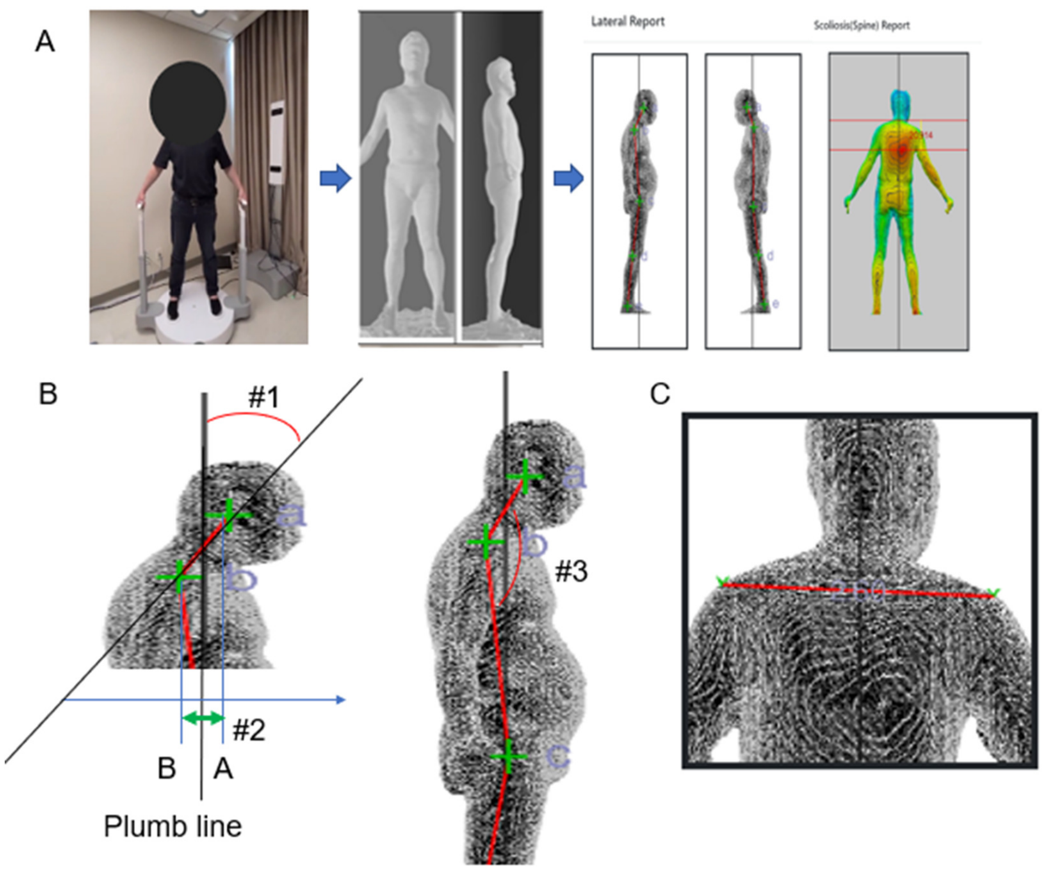

Figure 1. A. Full sequence of 3D scanner measurement, 3D surfacing technique and automated labelling of inflection points. B. Three concepts to measure sagittal balance. #1. Angle of two points with respect to the plumb line ex) aAB_sag #2. Horizontal distance between two points ex) dAB_hor #3. Angle of three points ex) angle of ABC, BCD, CDE C. Shoulder gradient to measure coronal balance.

2.5. X-ray and Other Measurement

Whole spine x-ray images were both AP and Lateral view covering whole vertebras and pelvic bone and gained as a routine way in our hospitals. Participants stood alone with their hands-on shoulders to show vertebral bodies well in the lateral x-ray view especially. We chose C2-7 SVA (sagittal vertical axis) and T1 slope as cervical parameters, SVA (Sagittal vertical axis) as global parameter and ODHA (Odontoid to Hip Axis) as cervical and global parameter. We also checked the spinopelvic parameters including the pelvic incidence (PI), pelvic tilt (PT), sacral slope (SS), lumbar lordosis (LL), PI-LL mismatch. Clinical questionnaires included the modified Oswestry Disability Index (ODI) to evaluate the degree of activity interference due to pain. We also checked the demographic factors including the ages, height, weight, BMI(Body Mass Index), PBF(Percentage Body Fat) and SMI(skeletal muscle index).

2.6. Data collection and Statistical Analysis

Whole spine x-ray images were measured by two orthopedic doctors. X-ray images were on PACS viewer. The intraclass correlation coefficient was 0.96 and we used the mean values. 3D scanning procedures were performed from one to four times per participant to reduce a risk of data processing problem, because this study was a preliminary study. To confirm the results between multiple measurements, the intraclass correlation coefficient between the results of multiple imaging was calculated and it was 0.93 and we used the mean values too. All data were analyzed using Rex pro 3.6.0 (Rexsoft, South Korea).

2.5. Funding

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3. Results

3.1. Correlation coefficient for the Cervical sagittal balance (Figure 2)

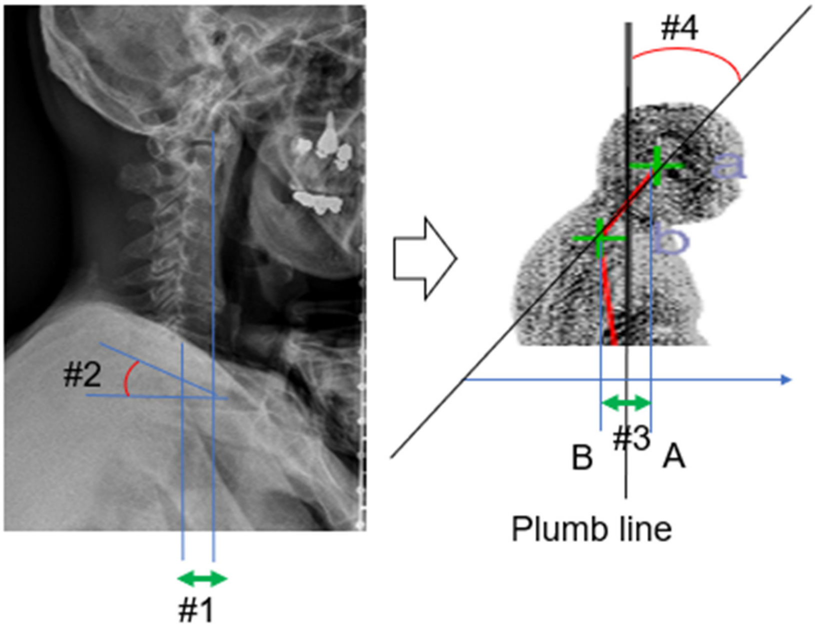


Figure 2. #1. C2-7SVA, #2. T1slope on x-ray, #3. dAB_hor, #4. aAB_sag on 3D sacnner

Sagittal plane analysis using a 3D scanner revealed correlations between the angle of AB with respect to the plumb line (aAB_sag), and cervical kyphosis (C2-C7 SVA, T1 slope). The correlation coefficients and p-values were 0.496 and <0.0001 for the C2-C7 SVA and 0.281 and 0.005 for the T1 slope. Similarly, the horizontal distance between points A and B(dAB_hor) was correlated with cervical kyphosis, and the correlation coefficients and p-values were 0.478 and <0.001 for the C2-C7 SVA and 0.276 and 0.006 for the T1 slope.

3.2. Correlation coefficient for the Global sagittal balance (Figure 3)

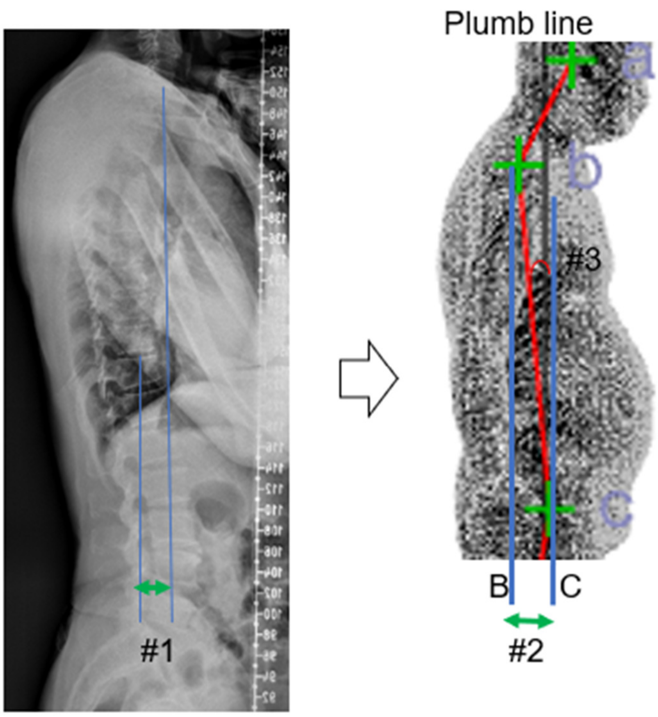
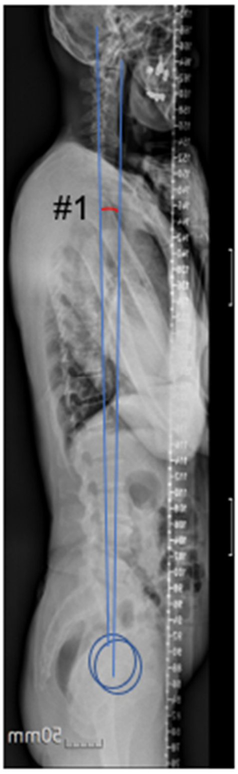


Figure 3. *#1. SVA on x-ray, #2. dBC_hor, #3. aBC_sag on 3D scanner*

The angle between the line BC and the plumb line (aBC_sag) was correlated with SVA, which is one of parameters representing global sagittal balance, with correlation coefficients and p-values of 0.22 and 0.029. Also, the horizontal distance between points B and C (dBC_hor) was related to SVA and the correlation coefficients and p-values were 0.222 and 0.028, respectively.

3.3. Correlation coefficient for the Cervical and Global sagittal balance (Figure 4)



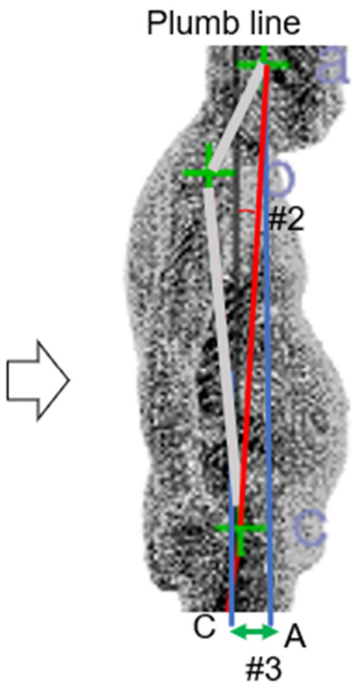
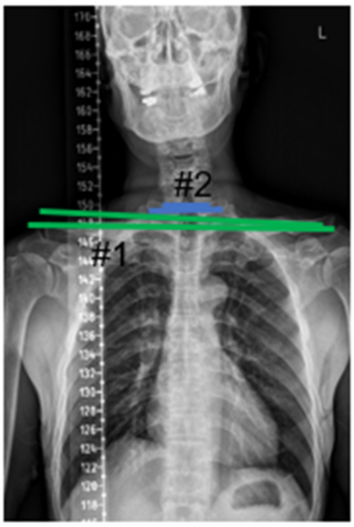


Figure 4. #1. ODHA on x-ray, #2. aAC_sag, #3. dAC_hor on 3d scanner

The angle between the line AC and the plumb line (aAC_sag) showed correlation with ODHA and the correlation coefficients and p-values were 0.34 and <0.001. Likewise, the horizontal distance between point A and C (dAC_hor) was related to ODHA, with correlation coefficient and p-value of 0.33 and <0.001, respectively.

3.4. Correlation coefficient for the coronal balance (Figure 5)



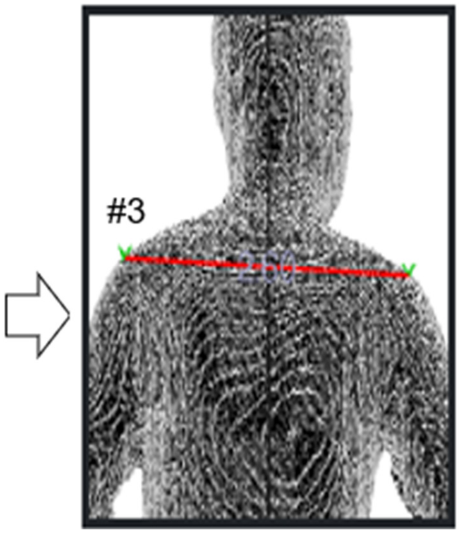


Figure 5. #1. Clavicle angle, #2. T1 coronal tilt on x-ray, #3.Shoulder gradient on 3d scanner

The shoulder gradient in the coronal plane was correlated with the clavicle angle of the x-ray, and the correlation coefficient and p-value were 0.37 and <0.001. The correlation between the shoulder gradient and T1 coronal tilt exhibited lesser correlation coefficient and higher p-value, which were 0.25 and 0.015, respectively.

3.5. Correlation coefficient for the neck flexion, hip flexion, knee flexion on 3d scanner

We first assumed that the angle of ABC, BCD, CDE would reflect the neck flexion, hip flexion and knee flexion respectively. But the angle of ABC didn't show any correlation with cervical flexion parameters. The angle of BCD (aBCD) didn't showed statistically significant correlation with the spinopelvic parameters related to the hip flexion. On the other hand, aBCD was found to be associated with SVA, the global sagittal balance parameter, as reflected by a correlation coefficient of -0.26 and a p-value of 0.010. It shows that positive sagittal balance has a relationship with hip flexion. We couldn't compare the angle of CDE, knee flexion angle, with similar knee flexion parameters in the x-ray because whole spine x-ray images couldn't contain the knees. But aCDE was found to be associated with SVA, as reflected by a correlation coefficient of 0.30 and a p-value of 0.003 and also associated with lumbar lordosis, as reflected by a correlation coefficient of -0.31 and a p-value of 0.002. This could be related with compensatory knee flexion mechanism dealing with the positive sagittal balance.

3.6. Partial correlation coefficient between two parameters.

We assumed that the correlation coefficient between C27 SVA and dAB_hor should be higher because two parameters were measured in a similar way. And maybe the difference between body surface and bone structure would be present due to obesity.[3, 4] Partial correlation was performed to use the correlation between x-ray and 3D scanner, excluding the effect due to obesity. We used BMI score and PBF score respectively. The partial correlation coefficient and p-value of dAB_hor excluding the BMI score were 0.474 and <0.001 for the C2-C7 SVA, which is not different with the previous one. The partial correlation coefficient and p-value of dAB_hor excluding the PBF score were 0.39 and <0.001 for the C2-C7 SVA, which is statistically significant but different with previous data.

Also, we assumed that the correlation coefficient between SVA and dBC_hor should be higher too. We did the same procedure. The partial correlation coefficient and p-value of dBC_hor excluding the BMI score were 0.23 and 0.028 for the SVA, which is not different with the previous one. The partial correlation coefficient and p-value of dAB_hor excluding the PBF score were 0.23 and 0.023 for the SVA, which is not different with the previous one and slightly higher correlation coefficient.

We thought correlation coefficient between ODHA and aAC_sag should be in a same way. The partial correlation coefficient and p-value of aAC_sag excluding the BMI score were 0.34 and <0.001 for the ODHA, which is same with the previous one. The partial correlation coefficient and p-value of aAC_sag excluding the PBF score were 0.33 and 0.001 for the ODHA, which is not different with the previous one.

In conclusion, we concluded that BMI score and PBF score didn't affect the correlation between two parameters.

3.6. Clinical symptoms related to x-ray or 3D full body scanner parameters.

The severity of clinical symptoms was checked in two parameters, back pain VAS (visual analog scale) and ODI score (Oswestry disability index, 0-45). The correlation coefficients and p-values of VAS were -0.22 and 0.03 for the Lumbar lordosis and 0.25 and 0.01 for the sacral slope. The correlation coefficients and p-values of ODI were -0.28 and 0.005 for the Lumbar lordosis, 0.27 and 0.007 for the PI-LL mismatch and 0.22 and 0.034 for the SVA. The loss of lumbar lordosis is known for a reason of back pain, including the disc space narrowing or the sequalae of compression fracture.[5] Sagittal imbalance is also known for a cause of back pain and parameters related to it such as PI-LL mismatch and SVA would be related to the clinical symptoms.[1] However, there were no 3D scanner parameters related to clinical symptoms excepts angle of BCD and CDE. The correlation coefficient and p-value of aBCD for the ODI score were -0.21 and 0.04 and aCDE for the ODI score were 0.25 and 0.01. Maybe aBCD has a relationship with SVA and aCDE has it with SVA and lumbar lordosis too. The partial correlation coefficient and p-value of aBCD for the ODI score excluding the SVA were -0.16 and 0.12, which is not statistically significant. The partial correlation coefficient and p-value of aCDE for the ODI score excluding the SVA and lumbar lordosis were 0.16 and 0.11, which is not statistically significant.

4. Discussion

This study was the first to measure the sagittal and coronal balance of the spine using a newly developed 3D full body scanner. As a preliminary study, this study has limitations and many things that needed to be improved. However, this study has its strength because it has some different points with other studies. First, as far as we know, there was no study to use a 3D full body scanner for sagittal and coronal balance. There are some studies using surface topography but some specific topography machines are needed and optional infra-red adhesive markers are needed.[2] In our study, a 3D full body scanner doesn't need special markers and can be used for other intend like calculating the circumference of body surface. Using no special markers could lessen the financial burden, escape from ethical and legal issues (touching someone's body) and minimize the risk of contact induced infection or skin problem. Second, previous studies focused on checking the change of adolescent idiopathic scoliosis, which means the participants are young and don't have a lumbar degenerative change. But in our study, we collected a variety of participants and our mean age was 65. So, we could focus on lumbar degenerative change like checking lumbar lordosis or PI-LL mismatch. Third, we checked BMI and PBF because previous studies proposed that surface topography images should be affected by body surface morphology like obesity. Some studies only involved young and slim participants for the accuracy of protocol.[6] But to involve the participants with lumbar degenerative disease, we chose to check BMI and PBF also and used partial correlation coefficient. Finally, we checked lumbar VAS and ODI to evaluate the possibility of 3D scanner as an additional device for clinical diagnosis and treatment.

The correlation between 3D scanner and X-ray parameters is higher for cervical sagittal balance than for global sagittal balance. This could be attributed to the difference in imaging posture used in 3D scanner and X-ray. In the 3D scanner, the patient stood with both hands on the handle, whereas in the X-ray, the hands were placed on the shoulders. Position difference is present under the shoulder level, which affects less on cervical parameters. Additionally, the point A is comparable to C2, and the point B is dissimilar to C7 but the difference is not severe. However, the point C is significantly different from the posterior sacrum and influenced by factors such as height and pelvic size. The parameters made with lower inflection points, B or C could be affected more. Consequently, the difference in global sagittal balance parameters between the 3D scanner and the X-ray is greater than that of cervical sagittal parameters.

The difference between the parameters of the 3D scanner and the X-ray was due to the difference in imaging posture and the many confounding variables that come into play during a 3D scan acquisition. As mentioned, the position of the hands and the presence or absence of a grip can vary, and a person's posture can change from one measurement to another. During 3D scanning, handles are used for preventing the fall down due to the rotating moment. There is no consensus of the golden standard position in x-rays. There are some studies about the positioning difference during x-rays.[7]More follow up studies are needed to evaluate.

The aBCD was related to the SVA, which represents global sagittal balance, because the increase of lumbar kyphosis leads to the decrease in aBCD in the presence of forward postural tilt. And that is the reason why the aBCD had a correlation with the ODI score which was relationship with SVA. The aCDE was related to the SVA and lumbar lordosis too. This is very important result because it looks relevant to the compensatory knee flexion mechanism. To keep a sagittal balance, patients with positive sagittal balance tend to flex their knees.[8] Normal whole spine x-rays don't cover both knees and this could result in difficulties of checking this mechanism. But a 3D full body scanner could help to check this mechanism.

This study has some limitations. First, the number of participants was small. Second, to do a full body scanner, participants should wear only fitted pants and tops. This could be a problem of privacy and lead to a tendency of reluctancy to our study. Third, as mentioned, the position during scanning is different with x-ray's one. As a preliminary study, we will focus on how to correct it. Finally, the correlation coefficients were not that big. But we knew that whole x-ray images are now the golden standard but they have limitations to capture actual status of sagittal and coronal balance. As a preliminary study, we will focus on the relationship between 3D full body scanner and x-ray images.

5. Conclusion

The sagittal and coronal balance parameters measured using a 3D scanner showed statistically significant correlations with the X-ray parameters. The 3D scanning method is capable of analyzing spinal balance while having no radiation and reflecting physiologic position. However, the correlation with spinal pain was relatively low, which is inferred to be due to the positional difference. Clinical symptoms were related to the spinopelvic parameters from x-ray. But this scanner has strengths including radiation free procedure and compensatory knee flexion mechanisms.

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