Monitoring scoliosis progression

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Chapter 4

The Best Arm Position for a Reproducible Posture during Spinal X-ray Radiography

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Abstract

An irreproducible posture of scoliotic patients during X-ray radiography may cause unreliable and inaccurate measurement of the spinal deformity while following scoliosis progression. A balancing device, the *BalancAid*, was developed to force the subject to stand upright and balanced. This resulted in a minimal variability of standing posture and therefore it is a promising tool to acquire good posture reproducibility. However, to realize highly-reproducible X-ray radiography, the standing posture needs an optimal arm position. The objective of this study is to investigate the arm position which represents the best reproducible standing posture. A prospective analysis of the reproducibility of the standing posture with photographs of healthy young female subjects was performed by examining 5 different arm positions. The posture reproducibility was determined on photographs of posterior-anterior (PA) and lateral (LA) view by analyzing body mark positions on 11 healthy subjects using 5 different arm positions: Fists on clavicle position (FC), fists on shoulder (FS), fists on clavicle with stick (FCS), fists on shoulder with stick (FSS) and shoulder flexion of 90˚ with counterweight (CW). Bland Altman plots and Friedman tests have demonstrated that FS and FCS resulted in the most reproducible posture in PA-view. In LA-view, no particular position resulted in the most reproducible posture with the Bland Altman plotting method. However with the Friedman method, FCS was found to be the most reproducible posture in LA-view. In conclusion, the FCS while standing on the *BalancAid* is the best position for a reproducible posture during spinal X-ray radiography of the spine.

Keywords

Arm position, reproducible posture, *BalancAid*, spinal X-ray radiography, scoliosis progression

4.1. Introduction

The progression of scoliosis is generally investigated twice a year [1] by taking full spinal X-ray radiographs in both PA- and LA-views [2] in standing posture. From these X-rays, the lateral deviation, vertebral rotation, and sagittal alignment can be determined [3-5]. However, variabilities occur even when these measurements are performed in quick succession. Two possible causes are known for this variation: patient positioning and measurement inaccuracies on the X-rays [6]. Regarding the positioning, some studies investigating the patient's postural and positional differences have found that small changes in posture and position influence the position of body structures on X-rays, especially axial rotations [7], and cause errors in the measured curvature [8-12]. These studies have shown that subject positioning is one of the major sources of error, and therefore posture reproducibility plays an important role in generating a reliable and accurate comparison of serial X-rays.

Another cause of positional error may arise due to arm position differences between the PA- and LA-postures. The visibility blocking of the vertebral landmarks in the LA-view necessitates different arm position than in PA-view. These arm position differences bring about errors. Firstly, arms position inconsistency during one X-ray-session may interfere with reproducibility. Secondly, free hanging arm in PA-view may contribute to posture variability [8].

To overcome the vertebral visibility disturbance, previous investigations have proposed several arm positioning strategies which produce an optimal arm position, including relaxed hanging arms, various degrees of shoulder flexion with and without arm support, and holding the fists on the clavicle [13-18]. Studies on the fists on clavicle position have shown that this position generally demonstrates a more functional sagittal profile concomitant with sufficient vertebral visibility [15-18]. Additionally, Marks et al. have suggested that passive shoulder flexion of 30° resulted in a better sagittal alignment [5]. However, the abovementioned studies were focused on the arm position for X-rays in only LA-view.

A proper subject positioning during X-ray radiography has been endorsed by Scoliosis Research Society (SRS) to acquire reproducible spinal X-rays [2]. Additionally, this recommendation has suggested aligning the subject by means of a positional supporting device. The use of such positional support is commendable, not only to align the subject's global axis system with the film plane, but also to minimize postural variability.

For the purpose of improving the standing posture reproducibility, the *BalancAid* (Figure. 3.1 of Chapter 3) has been developed. By using the see-saw principle, this device forces a person standing on it to attain a single balanced posture with the center of mass always at a constant location. In addition, it directs the posture in a specific upright position and therefore a more reproducible posture is acquired. The study of Dewi et al [19], has demonstrated that the posture standing on this balancing device provides improved reproducibility compared to the commonly used posture standing on the ground. Hence, the *BalancAid* is promising in reproducing the posture.

Seeing that different arm position in both PA- and LA-views may trigger variability, prescribing one arm position for both views for standing on the *BalancAid* is likely to improve the posture reproducibility. In the future, this can also be beneficial for three-dimensional imaging (3DUS) systems of the spine (e.g; the EOS system [20]) which applies one arm position for both views to be taken in one time. However, this best arm position is still open to question.

In this study we investigated 5 different arm positions and determined the optimal arm position for both views to apply on the *BalancAid* to avoid posture irreproducibility.

4.2. Materials and Methods

Patients

Eleven healthy young female volunteers from a university student population were included in this study (age: 22.6±1.8 [19-25 years old]; height: 1.69±0.07 [1.62-1.77 cm]; weight: 63.5±6.1 [58-78 kg]; average±standard deviation [range]). All subjects signed informed consent form. The exclusion criteria were being male, unable to stand without support devices and back pain.

Measuring Set-up

The *BalancAid*, as shown in Figure. 3.1 of Chapter 3, consists of a flat square wooden board (50×50×1 cm), with a disk made of wood (7 cm diameter, 2 cm height) placed on the bottom side in the centre point. On the top side, the board was marked with an angle of 22.5° from the midline to generate a neutral standardized stance (45° between both feet). It is necessary to position both feet at the same distance from the midline in PA-view to keep the centre of mass above the centre point of the *BalancAid*. Moreover, the distance between the feet in LA-view was taken into account. The heels of both feet were located in the same position (in LA-view, the angle joint was exactly located above the midline on the *BalancAid*) [9].

The best arm position was identified by analyzing the reproducibility of the standing posture. In order to mimic the X-ray radiography procedure with the absence of radiation exposure, body marks and ordinary photography methods were used.

The body marks were applied to quantify the body posture; twelve markers were placed, eight on the back and four on the trunk side, directly on the subject’s skin (see Figure. 3.4 in Chapter 3). We employed a rectangular grid of 3 mm dots drawn on small pieces of adhesive tape (1 cm by 1cm). The markers were approximately located at both sides of T3, T7, T12 and L4 of the spine. These points were determined by the top and bottom of the scapula (point 1-4), the vertical line of the previous point at the last ribs (point 5-6), and the top of the sacrum (point 7-8). Additionally, point 9-12 were located at the same height as the points on the back. Two digital cameras acquired the photographs of the body marks in PA- and LA-views simultaneously. Both cameras were located perpendicularly at distance of 1 meter from the *BalancAid* as illustrated in Figure. 3.3 in Chapter 3. Camera height was adjusted to the height of the center point between body marks 3, 4, 5, and 6 of each subject.

Protocol

For each subject, photographs were acquired in 5 different arm positions (see Figure. 4.1):

- **Fists on clavicle position (FC)**: Elbows were fully flexed and fists were placed on the medial part of clavicles, as studied previously [5,15,17,18]. The distance between the fists and the degree of shoulder flexion was measured.
- **Fists on shoulder (FS)**: Elbows were fully flexed and fists were placed on the shoulder joint. Again, the distance between the fists and the degree of shoulder flexion was measured.
- **Fists on clavicle with stick (FCS)**: Elbows were fully flexed and hands grasp a stick with the palm facing to the body. The stick is a wooden rod with 2.2 cm diameter and 58 cm length. The distance between the hands and the degree of shoulder flexion were taken equal to that of position 2.
- **Fists on shoulder with stick (FSS)**: Elbows were fully flexed and hands grasp the stick as described in position 3. The distance between the hands and degree of shoulder flexion was taken equal to that of position 2.
- **Counterweight (CW)**: Elbows were fully extended with a shoulder flexion of 90°. The arms were rested on a stick at a small distance distal of the elbow joint. In the middle, a rope was attached to the stick and a counterweight was attached through a pulley at the end of the rope. The system was accommodated to differences in arm mass by sliding the supporting stick under the arms until the arms did fully rest on the stick [21].

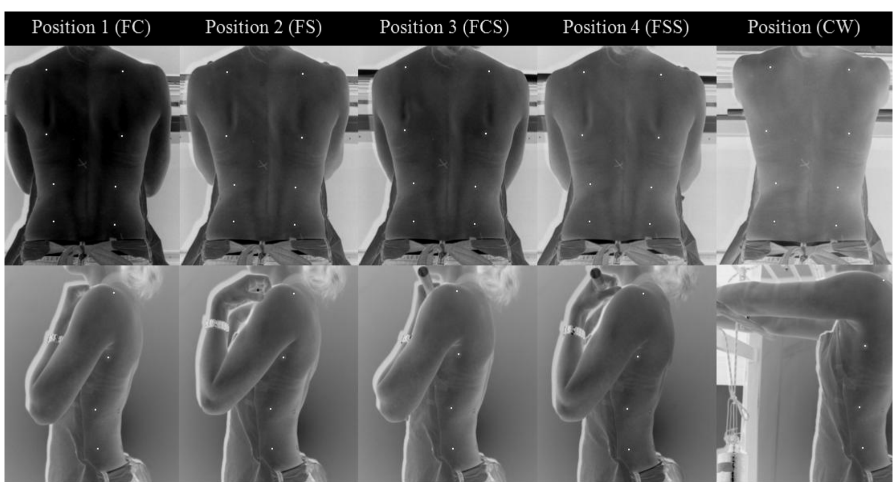


Figure 4.1. Five arm positions tested in this study in PA- (top) and LA- (bottom) views while standing on the *BalancAid*.

The photographs of the body marks in both views were established while the subject was standing on the *BalancAid*. To investigate the reproducibility, the photographs were acquired twice with 30 minutes delay. During the break, the subjects were asked to step off the *BalancAid*. No body mark repositioning was accomplished to avoid measurement bias. The feet were positioned the same at these two measurements based on the marking of the foot midline and the distance between the feet.

The posture reproducibility measurement on all arm positions was performed by examining the body marks photographs. For every photograph, the coordinates of each point were determined by mouse-clicking on the center of the points; the angles between the lines through the body marks were calculated to represent the body posture. The error in angle measurement was estimated to be less than 0.3° (based on the error in determining one body mark). Differences in posture were quantified by the changes of the angles between lines through the body marks. The reproducibility was determined by comparing the angles of the two measurements.

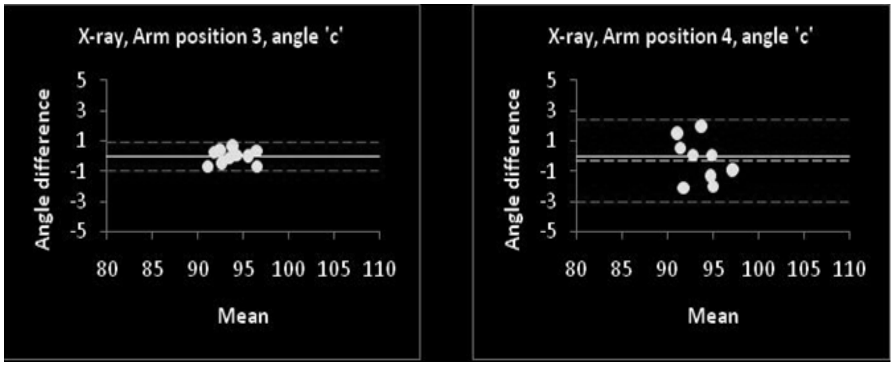
Statistics Calculation

The posture reproducibility in different arm positions was analyzed by using Bland Altman's 'limits of agreement' [22]. It is expected that 95% of the differences (between the angle of the first and second measurement) lie within the limits of agreement. The limits of agreement were determined by the $mean_{difference} \pm 1.96 * standard\ deviation_{difference}$. For each subject and all different positions, the differences between the values of each angle from the first and the second measurement were determined. The differences between the angles were visualized as a scatter plot including the lines of the limits of agreement and the mean of the difference. The reproducibility of the posture of the upper body was determined from the range between the limits of agreement. The posture with the smallest range and the mean closer to zero was concluded as the best reproducible posture for a specific angle.

In addition to the Bland Altmand plotting, the Friedman non-parametric test was applied to compare the reproducibility of all tested arm positions in a rank-based manner. For each angle, the five arm positions were ranked according to the standard deviations of the differences. The lowest rank indicates the best agreement [2].

4.3. Results

During the intermission, body mark point 12 of subject 7 and point 4 of subject 10 were deleted. The adhesive tape was unintentionally removed, and therefore the difference of respectively angles q and r and angles b, c, d, e, f, and h could not be measured for this subject.



(a) (b)

Figure 4.2. Bland Altman plots of angle *c* for position 3 (a) and position 4 (b).

The standard deviation of the calculated angle differences for all angles and positions are presented in Table 4.1. The Bland Altman plot presented in Figure. 4.2a demonstrates the limits of agreement for FCS angle c which has the smallest standard deviation, while the Bland Altman plot in Figure. 4.2b shows the limits of agreement for FSS angle c, which has a larger standard deviation. The most reproducible position was determined by the smallest limits of agreement in the Bland Altman plot. Best position candidates were marked if small differences (≤0.4 degree) between the limits of agreement for the specific different positions were found. The results are listed in Table 4.2. The limits of agreement confirm the agreement how much the tested methods are likely to differ from the others.

Table 4.1: Standard deviation of the differences between angles for each position

PA-view					
Angle	**(1) FC**	**(2) FS**	**(3) FCS**	**(4) FSS**	**(5) CW**
a	1.4	1.1	0.7	1.5	1.3
b	1.2	1.6	1.0	1.0	1.7
c	1.2	1.1	0.5	1.4	1.1
d	0.9	1.4	1.0	1.0	1.8
e	1.8	2.3	1.2	1.0	0.7
f	1.6	0.8	1.5	2.1	1.8
g	1.6	1.7	0.8	0.9	1.0
h	1.3	0.9	1.4	1.8	1.4
i	1.4	0.7	1.6	1.4	1.5
j	1.3	0.6	0.9	0.7	1.7
k	1.0	0.8	1.5	1.5	1.3
l	1.2	0.7	1.1	1.0	2.1
LA-view					
m	3.4	2.6	2.9	1.9	4.1
o	3.7	3.6	3.4	5.0	3.9
q	1.6	2.2	2.2	2.6	4.1

Table 4.2: Scoring of the arm positions for each angle.
The '×' sign represents the best position candidates of each angle.

PA-view					
Angle	**(1) FC**	**(2) FS**	**(3) FCS**	**(4) FSS**	**(5) CW**
a			X		
b	X		X	X	
c			X		
d	X		X	X	
e				X	X
f		X			
g			X	X	X
h		X			X
i		X			
j		X	X	X	
k	X	X			
l		X			
LA-view					
m				X	
o		X	X		
q	X				

Subsequently, the results of the Friedman test, for both PA- and LA-views with a *p*-value of 0.25, are given in Table 4.3. This *p*-value explains that we cannot reject the null hypothesis of no differences significantly. From this result we can only see that one method is likely to be better than the other methods.

Table 4.3: Values of the Friedman method.
The smaller the mean rank, the more reproducible the position

PA-view	
Position	**Mean Rank**
FC	3.12
FS	2.38
FCS	2.58
FSS	3.25
CW	3.67
LA-view	
FC	2.67
FS	2.17
FCS	2.17
FSS	3.33
CW	4.67

4.4. Discussion

Positioning inconsistency has been reported to cause variability in Cobb angle measurement [8,9,10]. The study of Dawson et al. has testified a wide variability of Cobb angle during free standing [8]. This finding has been strengthened by subsequent studies [6,9,10,11,12] about the Cobb angle measurement differences due to postural variabilities.

In view of the fact that posture irreproducibility may cause inaccuracy which could lead to wrong diagnosis, it is crucial to follow the SRS recommendation on the use of a supporting device to position the patient in a more reliable way in spinal X-rays. The *BalancAid*, a balanced-positioning device, has led to an improvement in generating a standing posture reproducibility. With the advantage of employing no arm supporting bars to align the position, this supporting device also enables the spinal X-rays to be taken in one acquisition for both views or even during 3DUS imaging of the spine. However, since this is a new method of standardizing standing posture in spinal X-rays, no arm positioning has been investigated.

Currently, X-rays of the scoliotic spine are usually examined in different arm positions (arms relaxed to the side for PA-view and arms raised with a shoulder flexion of 90˚ for LA-view, respectively). However, seeing that difference in positioning the arms may trigger postural irreproducibility and measurement inaccuracy [5,13-18], it is worthwhile to position the arms in a way that is suitable for taking X-rays in both the LA- and PA-directions. In a 3D system, X-rays can be acquired simultaneously and any unnecessary movements which may cause postural error can be omitted.

In this study, we tested 5 different arm positions to determine the most reproducible posture on the *BalancAid*, so that the best arm position can be applied for both PA- and LA- views of X-rays, 3D reconstruction of the spine, and for the EOS system. By using the *BalancAid*, the influence of variation in posture was excluded for a large extend. Therefore, posture variation was mainly caused by differences in the arm position. A drawback of the *BalancAid* is that it generates a non-functional relaxed standing position. However, the reproducibility can be increased and accurate diagnosis of the spinal deformity progression can be obtained in a more definite way.This study was done with healthy young female subjects, hence it may represent only female patients with early scoliosis.

In Table. 4.1 and Table. 4.2, we indicated the angles with the smallest standard deviation and represented the reproducibility based on the standard deviation of the angle, meaning the smaller the standard deviation value, the more reproducible the angle. The most reproducible arm position is the one in the column with the highest number of angles with the smallest standard deviation. The most reproducible angle is obtained by finding the row with the most frequent arm position with the smallest standard deviation. Regarding finding the most reproducible arm position in PA-view based on the standard deviation of the differences between the angles for each position, position FS and FCS have the most angles with smallest standard deviation: angles f, h, i, j, k, and l for FS, and a, b, c, d, g , and j for FCS. Both FS and FCS score in that respect equally. For FCS, the scores are negatively influenced by outlier data from one value of one subject. Without this exception, the limits of agreement would turn to be greatly smaller and angle f, h, and l can be added to the smallest standard deviation angle group. Then FCS is the arm position with the most reproducible posture. In comparison to FC and FS, FCS is an easier and more prescribed way of standardizing the arm position..

In LA-view, we found no optimal arm position. In a previous study [19] it was also found that defining a reproducible posture in LA-view is more difficult to realize than in PA-view.

Regarding the most reproducible angle in PA-view, we found that angle b, d, g, h, and j have three arm positions with the smallest standard deviation, and angle o in LA-view has two arm positions with the smallest standard deviation,. In other word, these are the angles which are the least sensitive to changes in posture.

In addition, in the volunteers' subjective point of view, FS and FSS were experienced as uncomfortable and difficult to maintain. This was in contrast to FC and FCS, which were experienced as more comfortable and easier to perform.

With the Friedman nonparametric test, the most reproducible position was determined based on the smallest mean of the ranking of the standard deviation. In PA-view, FS has the lowest mean ranking of 2.38, followed by FCS with a mean ranking of 2.58, which is slightly larger than FS. In LA-view, FCS scores best. Considering all criteria, the FCS position is found to be the best position for posture reproducibility.

4.5. Conclusions

Tests on 5 different arm positions on healthy young female subjects standing on the *BalancAid* have shown that one position, FCS, results in the most reproducible posture in PA-view. The 'limits of agreement' in the LA-view have indicated no single arm position having the most reproducible posture. The Friedman test revealed that FS and FCS resulted in the lowest mean ranking in PA-view. In addition, FCS in LA-view have signified in the most reproducible posture based on the lowest mean ranking.

Therefore we recommend FCS as the best arm position for posture reproducibility during spinal X-ray radiography.

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