

1 **The Age-specific Normative Values of Standing Whole Body Sagittal Alignment Parameters in**
2 **Healthy Adults: Based on International Multicenter Data**

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4

5 **ABSTRACT**

6 **Purpose:** To investigate the age -specific normative values of whole body sagittal alignment
7 (WBSA) including global balance parameters in healthy adults and to clarify the correlations
8 among parameters based on the data from three international multicenter.

9 **Methods:** Three hundred and seventeen healthy subjects (range:20-84 y.o., mean:43.8 \pm 14.7
10 y.o.) were included and underwent whole body biplanar X-ray imaging system. Spinopelvic
11 parameters and knee flexion (KF), the center of acoustic meatus (CAM) -hip axis (HA), and C2
12 dentiform apophyse (OD)- HA, the cranial center (Cr)-HA were evaluated radiologically. Sub-
13 analysis for correlation analysis between age and parameters and among parameters were
14 performed to investigate age-specific change and compensatory mechanisms.

15 **Results:** For age-related change, C2-7 angle ($r = .326$ for male/.355 for female), KF (r
16 $= .427/.429$), and SVA ($r = .234/.507$) increased with age in both male and female group. For

1 global parameters related to the center of the gravity, correlations with age were not significant
2 ($r = .120/.161$ for OD-HA, $r = .163/.275$ for Cr-HA, $r = .149/.262$ for CAM-HA). Knee flexion
3 (KF) has correlation with global parameters (i.e. SVA, OD-HA, Cr-HA, CAM-HA) and doesn't
4 have correlations with local spinopelvic alignment.

5 **Conclusion:** While several local alignment changes with age were found, changes in global
6 parameters related to the center of gravity were kept relatively mild by the chain of
7 compensation mechanisms including the lower limbs. We showed the normative values for a
8 comprehensive WBSA in standing posture from large international healthy subjects' database.

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11 **Keywords:**

12 Global balance, Sagittal balance, Normative values, Healthy subjects, Whole body alignment

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1 **INTRODUCTION**

2 Sagittal alignment of the spine is widely recognized as a primary subject for preoperative
3 planning for spine surgery and many studies have reported strong correlations between these
4 spinopelvic parameters and clinical symptoms [1-5]. Many studies have shown that spino-pelvic
5 parameters, such as the sagittal vertical axis (SVA), T1 pelvic angle (TPA), and spinosacral angle
6 (SSA) are associated with the clinical manifestations and clinical outcomes in patients with spinal
7 disorders [1-3, 5-8].

8 In addition, the center of acoustic meatus (CAM) and C2 dentiform apophyse (OD), which
9 are indices of the center of gravity of the head have been used in several studies for the purpose of
10 evaluating whole body balance in standing posture [9, 10]. The index of the center of gravity in the
11 standing posture is reported to be constant in healthy cohorts, and is kept constant by several
12 compensation mechanisms. For compensation in standing posture for imbalance due to spinal
13 malalignment, parameters out of the range of the cervical spine to the pelvis (e.g., hip, knee, and
14 ankle) are sometimes mobilized [11, 12]. This whole body sagittal alignment (WBSA) consists of
15 many chains of balance from the foot to the cranium, and changes with degeneration and other spinal
16 morbidities [1, 4, 13]. Several studies have reported relationships between parameters—including

1 parameters out of the spino-pelvic range—and clinical outcomes and quality of life [5]. Kim et al.[3]
2 described the CrSVA index, which is the distance between a vertical plumb line from the cranial
3 center and the hip, knee, and ankle, and these are predictors that reflect the postoperative clinical
4 outcome more strongly than the SVA in patients with cervical myelopathy. The lower limb
5 parameters are also important compensation mechanisms in patients to maintain the standing posture
6 in patients with spinal degeneration [5, 14, 15]. Several previous studies have reported that the
7 alignment of the whole body, including the lower extremities, varies with age [1, 16, 17]. Hence, we
8 believe that the clarification of the age-specific normal alignment values of global whole body
9 sagittal alignment and their mutual relationship are important for evaluating and understanding
10 pathological alignment and balance abnormalities.

11 Several studies have reported age-specific normative values and correlations of whole-
12 body sagittal parameters, including lower extremity alignment [1, 11, 18]. Le Huec and Hasegawa
13 [16] reported normative values for WBSA, including knee flexion, in an international study of 268
14 asymptomatic subjects. In addition, Lyer et al. [19] and reported age-specific normative values for
15 WBSA in a study analyzing 115 asymptomatic volunteers. However, these studies had a limitation in
16 that the cohorts were biased toward younger age groups or were enrolled at a single institution.

1 Therefore, an international multicenter study has been anticipated to determine the age-specific
2 normative WBSA values in healthy subjects, including older subjects, and it was necessary to
3 investigate the correlation between changes in each parameter in a cohort that included elderly
4 individuals, especially the relationship between age-related changes in compensation mechanisms of
5 the lower extremities and spinal parameters.

6 The current study aimed to comprehensively investigate age-specific WBSA parameters in
7 a healthy population, to determine the normative values of these parameters, and to clarify the
8 correlations among parameters based on international multicenter data.

9

10 **MATERIALS AND METHODS**

11 We enrolled healthy subjects who were confirmed not to have any past and/or current
12 medical history of spinal disease with a questionnaire and the Oswestry Disability Index was
13 obtained for evaluation of clinical complaints [20]. The ODI score values were compared to previous
14 reports and validated for treatment as a cohort of healthy subjects. Subjects with neurological disease
15 or with joint disease affecting assessment in the standing posture were not included in this survey.

16 Participants underwent whole body X-ray using a scanning X-ray imaging system (EOS

1 Imaging, Paris, France). The examination posture was a "hands-on-cheek" posture in standing
2 horizontal viewing, and participants lightly touched their fingers and were instructed to relax as
3 much as possible during shooting.

4 This study was approved by the Institutional Review Board of each institution.

5

6 **Parameters of Whole Body Sagittal Alignment**

7 Whole body sagittal alignment from cranio-cervical junction to knee joint was analyzed in
8 this study. The occipito-C2 angle (O-C2 angle: McGregor line–C2 endplate) and C2-7 lordotic angle
9 (C2 endplate–C7 caudal endplate) for the cranio-cervical region; the T1 slope for the cervico-
10 thoracic region; upper thoracic kyphosis (Upper TK: T1-4), Lower TK (T4-12), and Global TK (T1-
11 12) for thoracic kyphosis; upper lumbar lordosis (Upper LL: L1-L3), Lower LL (L4-S1), and Global
12 LL (L1-S1) for lumbar lordosis; sacral slope (SS), pelvic tilt (PT), pelvic incidence (PI), and pelvic
13 thickness for the pelvic region; average knee flexion (KF: average of left and right knee flexion
14 angles) for the lower extremities; the sagittal vertical axis (SVA), OD-HA angle (angle between a
15 vertical line and the line to the most superior point of dentiform apophyse of C2 to the center of the
16 femoral head), Cr-HA offset (the distance from the plumb line from the cranial center of mass to the

1 center of the femoral head), CAM-HA offset (the distance from the plumb line from the acoustic
2 meatus to the center of the femoral head), T1 pelvic angle (TPA), spino-sacral angle (SSA: the angle
3 between the sacral plate and the center of C7 to the midpoint of the sacral plate), sagittal vertical axis
4 (SVA), cranial sagittal vertical axis (CrSVA: the distance from the plumb line from the cranial center
5 of mass to the posterior edge of the sacral plate) for global alignment. The cranial center of mass was
6 defined as the midpoint of the nasion-inion line (root of the nose to the external occipital
7 protuberance) as past reported [3]. The pelvic thickness means the sacroacetabular distance (the
8 distance from the posterior edge of the sacral plate to the center of the femoral head) [21, 22].
9 Kyphosis and lordosis are defined as the angle between the upper endplate of a selected vertebra and
10 the lower endplate of another selected vertebra. The parameters measured in this study are shown in
11 Figure 1.

12

13 **Data Analysis**

14 The SterEOS software program (SterEOS 1.6, Postural assessment workflow, EOS
15 Imaging) was used to measure the WBSA parameters.

16 We divided the subjects into three groups according to age (20s-30s, 40s-60s, ≥ 60 s) and

1 analyzed these results among age groups. As a sub-analysis of the study, to clarify differences in
2 parameters with age, we analyzed correlations between age and WBSA parameters by sex. Among
3 these parameters, SVA, OD-HA, Cr-HA, CAM-HA, TPA, and SSA were distinguished as global
4 parameters, and the mutual influence among each of the spinopelvic parameters and between
5 spinopelvic parameters and global parameters were investigated in a correlation analysis.

6

7 **Statistical Analysis**

8 IBM SPSS Statistics version 23.0 (IBM Corp., Armonk, NY, USA) was used for the
9 statistical analyses. All values are expressed as the mean \pm standard deviation. Pearson's correlation
10 coefficient (r) was used to measure the strength of correlations between each parameter, and between
11 age and each parameter. The strength of the correlation between each parameter was described using
12 the absolute value of r ($r=0.00-0.19$: very weak, $r=0.20-0.39$: weak, $r=0.40-0.59$: moderate, $r=0.60-$
13 0.79 : strong, and $r=0.80-1.0$: very strong). P values of <0.05 were considered statistically
14 significant.

15

16 **RESULTS**

1 **Study subjects**

2 A total of 317 subjects from three cohorts were included in this study (Table 1), including
3 206 Japanese adults and 111 Caucasian adults. The average age of the subjects included in the
4 statistical analysis was 43.8 ± 14.7 years, 60.6% of the subjects were female (n=192), and the
5 average ODI score was 4.3 ± 6.2 . The ODI score values were compared to previous reports (5.1-
6 10.2) and were determined to be acceptable for treatment as a cohort of healthy subjects [10] [20].

7

8 **Parameters of WBSA**

9 The results, including the mean and standard deviation of all measured parameters
10 according to age are reported in Table 2. The mean spinopelvic parameters were as follows: O-C2
11 angle, $15.9 \pm 8.1^\circ$; C2-7 lordotic angle, $1.3 \pm 12.6^\circ$; T1-slope, $22.7 \pm 8.4^\circ$; Upper TK, $11.1 \pm 6.3^\circ$;
12 Lower TK, $33.6 \pm 10.5^\circ$; Global TK, $40.5 \pm 10.8^\circ$; Upper LL, $11.3 \pm 10.5^\circ$; Lower LL, $35.2 \pm 7.1^\circ$;
13 Global LL, $54.1 \pm 11.5^\circ$; SS, $38.2 \pm 8.4^\circ$; PT, $12.6 \pm 7.6^\circ$; PI, $50.8 \pm 10.9^\circ$; and Pelvic thickness,
14 10.8 ± 0.9 cm. We also described the average values of the lower extremity and global parameters,
15 which were as follows: KF, $-0.8 \pm 5.5^\circ$; SVA, -0.2 ± 2.6 cm; OD-HA, $-9.9 \pm 20.6^\circ$; Cr-HA, -1.7 ± 2.9
16 cm; CAM-HA, -2.1 ± 3.0 cm; TPA, $8.0 \pm 7.6^\circ$; SSA, $129.1 \pm 17.2^\circ$; and CrSVA, 2.1 ± 2.6 cm.

1

2 **Correlation between Age and Parameters**

3 In both males and females, weak or moderate correlations were found in spinopelvic
4 parameters (i.e. C2-7 lordotic angle [male: $r=0.326$, $P=0.000$; female: $r=0.355$, $P=0.000$], T1 slope
5 [male: $r=0.242$, $P=0.007$; female: $r=0.279$, $P=0.000$], and KF [male: $r=0.427$, $P=0.000$; female:
6 $r=0.429$, $P=0.000$]). SVA (male: $r=0.234$, $P=0.009$; female: $r=0.507$, $P=0.000$) also showed a weak
7 correlation in males and a moderate correlation in females. Meanwhile, other global parameters (i.e.,
8 Cr-HA [$r=0.275$, $P=0.000$], CAM-HA [$r=0.262$, $P=0.000$], and TPA [$r=0.442$, $P=0.000$]) only
9 showed a correlation with age in females. Age-related changes in pelvic parameters (i.e., PT
10 [$r=0.357$, $P=0.000$], PI [$r=0.236$, $P=0.001$] and Pelvic thickness [$r = -0.316$, $P=0.000$]) were only
11 observed in females. We found that the ODI score was weakly correlated with age in both males and
12 females. The correlation between age and each parameter is shown in Table 3.

13

14 **Correlation among parameters**

15 The results of the analysis of correlation between spinopelvic parameters, and between
16 spinopelvic parameters and global parameters are summarized in Table 4. A very strong positive

1 correlation ($r=0.80-1.0$) was seen between T1 slope and Global TK ($r=0.800, P=0.000$), Lower TK
2 and Global TK ($r=0.833, P=0.000$), Global LL and SS ($r=0.817, P=0.000$), and PT and TPA
3 ($r=0.914, P=0.000$). A strong positive correlation ($r=0.60-0.79$) was seen between the C2-7 lordotic
4 angle and T1 slope ($r=0.658, P=0.000$), T1 slope and Lower TK ($r=0.627, P=0.000$), Upper LL, and
5 Global LL ($r=0.649, P=0.000$), SS and PI ($r=0.714, P=0.000$), PT and PI ($r=0.638, P=0.000$), and
6 PI and TPA ($r=0.636, P=0.000$).

7

8 **DISCUSSION**

9 This is the first multicenter international study to evaluate age-specific WBSA in a cohort
10 that included older subjects. This study presents the normative values for whole body alignment,
11 including lower limb and balance parameters, by age and sex in a healthy population and the
12 correlations among them.

13 Standing posture is made up of a chain of balance starting from the foot to the cranium.
14 Humans change their respective variable alignment and chain, keeping the center of gravity balance
15 within the range of the cone of economy with the minimum effort of the muscles and taking the
16 standing horizontal view posture[10, 23]. Amabile et al. [9] reported the constancy of CAM-HA and

1 OD-HA while cervical lordosis, PT, PI and SVA showed compensatory change in elderly people in a
2 study that compared asymptomatic young and elderly people. Even in the asymptomatic population,
3 the parameters that make up balance vary with age, but compensation for local alignment is provided
4 to equalize global balance parameters to maintain standing whole-body balance [9, 13, 16, 18]. If
5 spinal degeneration advances and eventually reaches a level that is outside the range of
6 compensation, and a collapse of global balance occurs, then the health-related quality of life
7 (HRQOL) declines [1, 2, 5-7, 24]. Hasegawa et al. [5] conducted a cluster analysis of three groups
8 with different compensatory status in WBSA (normal, compensated, and decompensated) and
9 reported differences in compensatory parameters among them and the association between the
10 compensatory status and the HRQOL score. The motivation of the current research is to investigate
11 the change of each parameter involved in the compensatory function for standing posture with age
12 and the correlations among the parameters. With the introduction of a new scanning X-ray imaging
13 system, the evaluation of comprehensive parameters, including head to feet, became possible with
14 low radiation exposure and high accuracy and several studies using this technique have reported the
15 parameters asymptomatic subjects [1, 10, 15, 18, 25]; however, such studies seem to have relatively
16 small study populations or include an age bias. The strengths of this study are that it included data

1 with unified standards from a large population with less age group bias and that a comprehensive
2 evaluation from the head to the lower extremities was conducted.

3 Regarding the spinopelvic parameters, the results of the present study were comparable to
4 values previously reported in the relevant literature [1, 9, 13, 18, 26]. The analysis of parameters
5 correlated with age, revealed that OD-HA, Cr-HA and CAM-HA were constant. Age was showed a
6 weak positive correlation with OD-HA and CAM-HA in female subjects but not male subjects. The
7 sex differences in this study may be due to a lack of statistical power due insufficiency of the elderly
8 age group in the male population. Age-related changes were observed in several parameters, even in
9 the asymptomatic healthy cohort. In both male and female group, age-related change was shown in
10 C2-7 lordotic angle, T1 slope, KF and SVA. Compensatory changes of local alignment in cervical
11 and lower extremities occur to maintain horizontal gaze in standing posture. Age-related changes in
12 cervical lordosis, TPA, SVA and increasing LL, pelvic anteversion and KF have been described in
13 previous reports [1, 9, 13, 18], which are almost compatible with the results of this study. The
14 cervical spine is one of the most variable compensation mechanisms [27, 28].

15 Interestingly, age-related changes in pelvic parameters, including PT and PI pelvic
16 thickness, were observed in females, and this tendency was not statistically significant in the males

1 in this study population, while these pelvic parameters have been often treated as an inherent value
2 of individuals. Vialle et al. [29] reported differences between male and female in PT, and Yukawa et
3 al. [13] reported that there was a significant difference of PT between male and female in the elderly
4 group. We hypothesized that the mechanism of degeneration of the sacroiliac joint differs between
5 males and females. Although the event considered to have had the most influence is pregnancy or
6 delivery [30], unfortunately the data of the present study did not include information on factors
7 affecting pelvic parameters, such as pregnancy history; thus, further investigation is necessary in the
8 future.

9 The analysis of correlation between parameters showed “strong” or greater correlations
10 between adjacent parameters, such as C2-7 lordotic angle and T1 slope, T1 slope and Global TK,
11 and Global LL and SS. Cervical spine alignment is the most substantial compensation mechanism
12 for maintaining the horizontal view because the viewpoint exists in the head [27, 28]. For this
13 reason, it is conceivable that T1 slope is strongly correlated with C2-7. Roussouly et al. [31] stated
14 that the inflection point located on the L1 level on average and the characteristics of lumbar lordosis
15 are highly dependent on the orientation of the sacral slope and the pelvis as a result of studies of
16 young asymptomatic populations. There are inflection points at each transition between cervical

1 lordosis, thoracic kyphosis, and lumbar lordosis, and a standing posture with minimum muscle effort
2 is maintained by the chain of each variable of spinal alignment. Despite numerous reports that state
3 that increased PT (i.e., retroversion of the pelvis) is an important compensatory parameter in
4 populations with spinal degeneration [7, 8, 12, 23], this study did not show any strong correlation
5 between PT and the parameters from the cervical spine to the lumbar spine. Similar findings were
6 found for KF. Parameters of the lower extremities, including the hip joint and knee joint are also
7 involved in compensation mechanisms in patients with sagittal imbalance [11, 12, 32]; it is
8 considered that mobilizing the compensation mechanism of pelvic retroversion or the lower limb,
9 including KF is a balancing mechanism for the entire spine rather than responding to certain local
10 alignment changes. As evidence to support this, KF was found to be correlated with almost all global
11 parameters (i.e., SVA, OD-HA, Cr-HA, CAM-HA, TPA, CrSVA).

12 The present study was associated with some limitations. First, this was a cross-sectional
13 study. In order to consider changes due to age, a longitudinal study should be conducted that
14 observes the same group. It is not strictly clear whether changes in parameters or group-specific
15 differences were due to age or occurred in the different age groups. However, it is impractical to
16 observe a large number of people over the long term using the same measurement methods. In

1 addition, the small number of cases in the elderly group could have resulted in statistical under-
2 power in the analysis of this study. Further studies with different designs are needed to infer the
3 process of spinal balance failure and to suggest factors in sagittal alignment that may cause the
4 exacerbation of imbalance.

5 Another limitation of the present study is that enrolled population included several races.
6 Le Huec et al. reported that pelvic parameters (PT, PT, SS) were comparable in comparative studies
7 of Caucasian and Japanese subjects; however, the data showed that LL, TK, KF differed between the
8 race groups [16]. The standard values shown in this study may be slightly erroneous when the same
9 values are applied to different races without adjustment. To address this problem, studies that include
10 larger subjects or a more homogeneous group of subjects are needed. However, we believe that the
11 correlation of these parameters that was shown in the present study will be useful for understanding
12 the compensation mechanism.

13 CONCLUSIONS

14 We showed the normative values for comprehensive whole body sagittal alignment in a
15 standing posture based on a large asymptomatic population database. In both men and women, C2-7,
16 T1 slope, KF, and SVA increased with age. In females but not males, age-related changes were found

1 in pelvic parameters, including PT, PI and pelvic thickness. There is strong correlation between
2 adjacent sagittal spinal parameters and KF, which was more associated with global parameters than
3 local spinopelvic alignment. From the findings in the healthy population, several local alignment
4 changes were found to occur with age, while changes in global parameters related to the center of
5 gravity were kept relatively mild by the chain of compensation mechanisms, including the lower
6 limbs.

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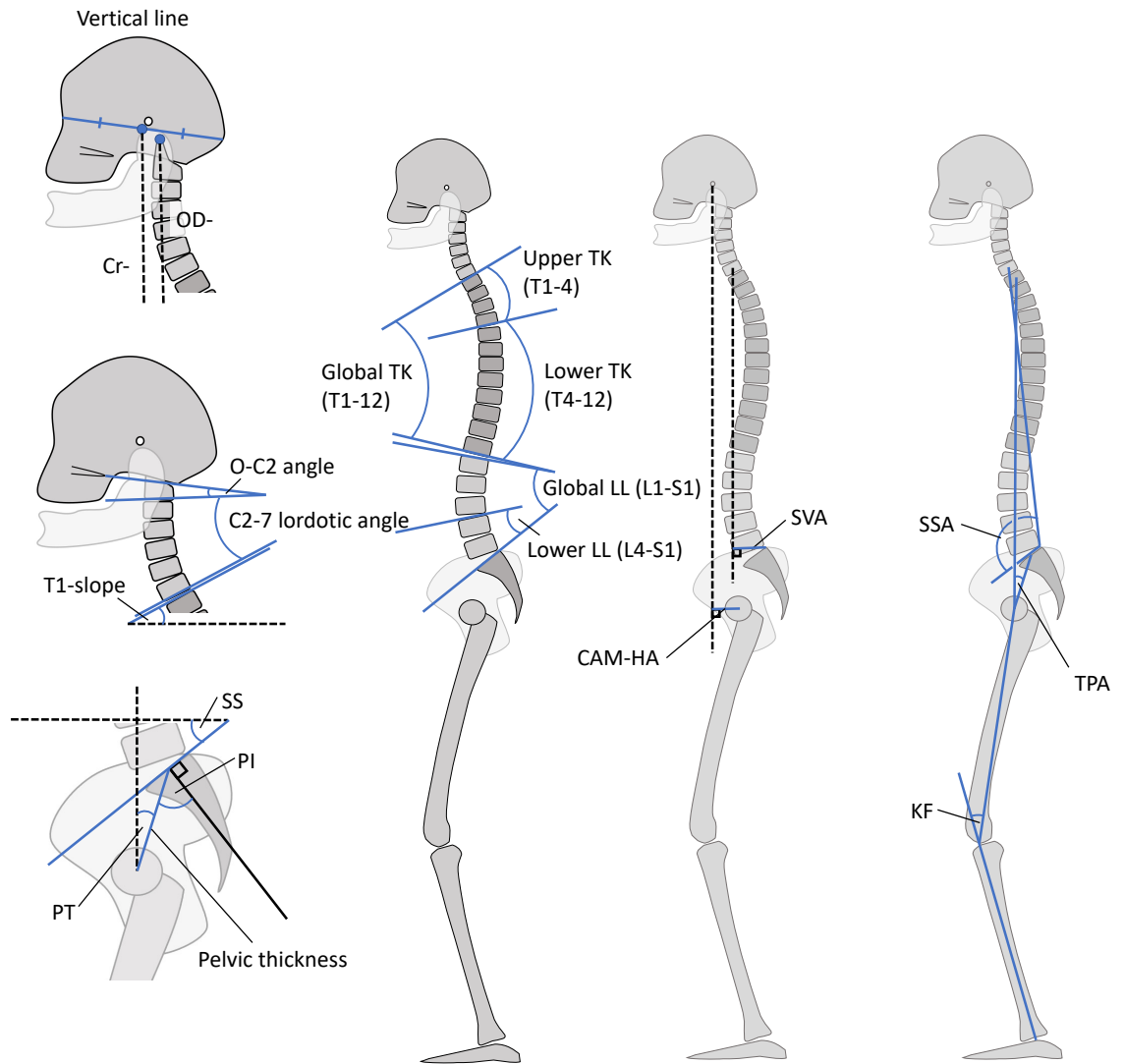
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1 **Figure legends**



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3 **Figure 1. Spinopelvic parameters and whole body sagittal alignment parameters**

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1 **Table 1. Baseline characteristics of healthy subjects from the three cohorts**

Characteristics	Total Sample		Cohort 1		Cohort 2		Cohort 3	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
No. of subjects	317		106		100		111	
Race			Mongoloid		Mongoloid		Caucasian	
Age (years)	43.8	14.7	52.6	12.3	39.4	12.1	39.2	15.2
Female, n (%)	192 (60.6)		76 (71.7)		63 (63.0)		53 (47.7)	
ODI score	4.3	6.2	8.0	7.4	4.3	5.4	0.7	2.2

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4 **Table 2. The mean and standard deviation of all measured parameters according to age group**

	Total		Male								Female							
	Mean	SD	Total (n=125)		20s-30s (n=62)		40s-50s (n=45)		≥60s (n=18)		Total (n=192)		20s-30s (n=74)		40s-50s (n=84)		≥60s (n=34)	
			Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
O-C2 angle (°)	15.9	8.1	15.6	7.6	15.3	6.6	16.3	8.1	14.8	9.8	16.1	8.4	17.1	9.9	15.6	7.3	15.2	7.8
C2-7 lordotic angle (°)	1.3	12.6	3.8	12.0	1.2	10.1	4.0	12.6	12.1	13.5	-0.4	12.8	-3.7	12.7	-1.2	10.8	8.8	13.7
T1-slope (°)	22.7	8.4	24.9	8.4	23.8	7.1	24.7	9.5	29.4	8.8	21.3	8.1	19.5	6.8	20.9	7.9	25.9	9.8
Upper (T1-4) TK (°)	11.1	6.3	13.0	6.6	12.6	6.1	12.5	7.1	15.4	6.9	9.8	5.8	10.7	4.8	9.7	5.9	8.1	7.1
Lower (T4-12) TK (°)	33.6	10.5	35.2	10.4	35.2	9.1	34.5	11.7	37.1	11.4	32.5	10.5	31.3	9.1	30.3	9.6	40.5	12.0
Global (T1-12) TK (°)	40.5	10.8	43.5	11.4	43.1	9.1	42.2	13.4	48.0	12.4	38.6	10.0	38.5	8.7	36.5	10.3	43.9	10.2
Upper (L1-3) LL (°)	11.3	10.5	11.8	10.5	13.3	10.4	11.1	10.1	8.1	11.0	11.0	10.6	11.9	9.6	10.6	10.8	9.9	12.1
Lower (L4-S1) LL (°)	35.2	7.1	36.4	6.1	37.4	5.4	35.1	6.9	36.4	6.4	34.4	7.6	36.0	7.1	32.7	7.3	35.1	8.9
Global(L1-S1) LL (°)	54.1	11.5	55.1	11.8	56.6	10.3	54.5	12.3	51.4	14.7	53.4	11.3	55.5	10.1	52.1	12.2	52.1	11.2
SS (°)	38.2	8.4	38.1	8.9	38.9	8.4	37.9	9.6	36.4	9.1	38.2	8.1	38.2	8.0	38.3	8.4	37.6	7.6
PT (°)	12.6	7.6	11.4	6.8	10.2	6.2	13.0	7.6	11.9	6.6	13.4	8.0	10.4	6.8	14.8	7.8	16.4	9.2
PI (°)	50.8	10.9	49.6	10.4	49.1	10.4	50.8	10.7	48.1	9.5	51.6	11.2	48.7	10.1	53.1	12.0	54.0	10.3
Pelvic thickness (cm)	10.8	0.9	10.6	1.0	10.6	0.8	10.6	0.8	10.9	1.9	10.8	0.7	11.1	0.7	10.8	0.7	10.5	0.7
Knee flexion (°)	-0.8	5.5	0.5	4.8	-1.7	4.5	2.1	4.1	3.8	4.2	-1.6	5.7	-4.5	5.5	-0.5	4.3	1.8	6.3
SVA (cm)	-0.2	2.6	-0.5	2.4	-1.0	2.1	-0.3	2.2	0.7	3.1	-0.1	2.8	-1.5	1.9	0.3	2.3	2.2	3.6
OD-HA (°)	-9.9	20.6	-10.1	20.4	-12.7	23.3	-8.5	17.1	-5.0	16.2	-9.9	20.8	-15.2	23.6	-6.2	16.5	-7.2	22.0
Cr-HA (cm)	-1.7	2.9	-1.7	2.8	-2.2	2.4	-1.5	2.7	-0.7	4.1	-1.7	2.9	-2.5	2.7	-1.5	2.4	-0.1	3.7
CAM-HA (cm)	-2.1	3.0	-2.2	3.0	-2.6	2.7	-2.2	2.6	-0.8	4.6	-2.1	3.0	-2.9	2.8	-1.9	2.6	-0.6	3.6
TPA (°)	8.0	7.6	6.7	6.2	5.7	6.0	7.8	6.7	7.7	5.0	8.8	8.2	5.1	6.3	10.2	7.9	13.2	9.6
SSA (°)	129.1	17.2	130.5	8.0	131.6	7.7	130.4	8.4	127.2	7.7	128.1	21.1	131.5	8.5	129.4	8.1	117.5	45.9
CrSVA (cm)	2.1	2.6	1.8	2.4	1.6	1.8	1.8	2.5	2.5	3.9	2.2	2.7	1.4	1.8	2.3	2.4	4.0	3.8
ODI score	4.3	6.2	2.8	4.5	1.7	3.8	3.6	4.7	4.4	5.3	5.3	6.9	2.2	4.3	6.9	7.2	8.1	8.3

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7 **Table 3. Correlation between age and whole body sagittal alignment parameters**

		O-C2 angle	C2-7 lordotic angle	T1-slope	Upper TK (T1-4)	Lower TK (T4-12)	Global TK (T1-12)	Upper LL (L1-3)	Lower LL (L4-S1)	Global LL (L1-S1)	SS	PT
Male	r	.020	.326	.242	.152	.055	.147	-.166	-.146	-.181	-.155	.176
	P	.822	.000	.007	.091	.543	.103	.065	.105	.043	.084	.050
Female	r	-.108	.355	.279	-.163	.244	.137	-.062	-.061	-.139	-.031	.357
	P	.137	.000	.000	.024	.001	.058	.396	.401	.054	.672	.000
		PI	Pelvic thickness	KneeFlex	SVA	OD-HA	Cr-HA	CAM-HA	TPA	SSA	CrSVA	ODI score
Male	r	-.020	.062	.427	.234	.120	.163	.149	.169	-.233	.117	.241
	P	.824	.491	.000	.009	.182	.072	.098	.060	.009	.198	.007
Female	r	.236	-.316	.429	.507	.161	.275	.262	.442	-.173	.349	.302
	P	.001	.000	.000	.000	.026	.000	.000	.000	.016	.000	.000

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1 **Table 4. Correlation among whole body sagittal alignment parameters**

		O-C2 angle	C2-7 lordotic angle	T1-slope	Upper TK (T1-4)	Lower TK (T4-12)	Global TK (T1-12)	Upper LL (L1-3)	Lower LL (L4-S1)	Global LL (L1-S1)	SS	PT	PI	Pelvic thickness	Average Knee flexion
C2-7 lordotic angle	<i>r</i>	-.470													
	<i>P</i>	.000													
T1-slope	<i>r</i>	-.061	.658												
	<i>P</i>	.280	.000												
Upper TK (T1-4)	<i>r</i>	.008	.241	.513											<i>r</i>
	<i>P</i>	.881	.000	.000											very weak 0.00-0.19
Lower TK (T4-12)	<i>r</i>	-.107	.493	.627	-.042										weak 0.20-0.39
	<i>P</i>	.057	.000	.000	.457										moderate 0.40-0.59
Global TK (T1-12)	<i>r</i>	-.100	.582	.800	.392	.833									strong 0.60-0.79
	<i>P</i>	.075	.000	.000	.000	.000									very strong 0.80-
Upper LL (L1-3)	<i>r</i>	-.137	.136	-.092	-.103	.284	.242								
	<i>P</i>	.015	.016	.103	.068	.000	.000								
Lower LL (L4-S1)	<i>r</i>	-.072	.126	.073	-.051	.305	.277	.038							
	<i>P</i>	.198	.024	.193	.363	.000	.000	.505							
Global LL (L1-S1)	<i>r</i>	-.099	.045	.000	-.016	.431	.407	.649	.538						
	<i>P</i>	.080	.429	.996	.770	.000	.000	.000	.000						
SS	<i>r</i>	-.024	-.064	-.071	.012	.126	.116	.444	.426	.817					
	<i>P</i>	.664	.257	.210	.832	.025	.040	.000	.000	.000					
PT	<i>r</i>	-.052	.162	.059	-.093	-.051	-.070	.049	-.244	-.153	-.082				
	<i>P</i>	.355	.004	.292	.097	.366	.211	.381	.000	.006	.144				
PI	<i>r</i>	-.056	.066	-.012	-.057	.063	.041	.378	.158	.525	.714	.638			
	<i>P</i>	.319	.242	.831	.309	.261	.463	.000	.005	.000	.000	.000			
Pelvic thickness	<i>r</i>	.102	-.162	-.024	.110	-.120	-.068	-.227	-.205	-.306	-.319	-.213	-.399		
	<i>P</i>	.069	.004	.670	.051	.032	.225	.000	.000	.000	.000	.000	.000		
Knee flexion	<i>r</i>	-.048	.177	.228	.057	.064	.075	-.140	-.116	-.155	-.068	.198	.087	-.080	
	<i>P</i>	.398	.002	.000	.313	.254	.180	.012	.039	.006	.225	.000	.124	.156	
SVA	<i>r</i>	-.037	.347	.433	-.091	.189	.078	-.074	-.286	-.230	.018	.342	.255	-.136	.327
	<i>P</i>	.517	.000	.000	.107	.001	.163	.187	.000	.749	.000	.000	.015	.000	.000
OD-HA	<i>r</i>	.131	-.092	.270	.149	.016	.040	-.414	-.209	-.183	-.005	-.077	-.058	.056	.247
	<i>P</i>	.019	.103	.000	.008	.773	.476	.000	.000	.001	.924	.172	.301	.320	.000
Cr-HA	<i>r</i>	.136	.091	.411	.016	.191	.141	-.188	-.101	-.136	.048	-.156	-.073	-.058	.306
	<i>P</i>	.016	.109	.000	.778	.001	.012	.001	.074	.016	.396	.006	.199	.307	.000
CAM-HA	<i>r</i>	.170	.074	.438	.037	.217	.168	-.187	-.108	-.114	.096	-.158	-.037	-.046	.285
	<i>P</i>	.002	.192	.000	.515	.000	.003	.001	.054	.042	.088	.005	.516	.415	.000
TPA	<i>r</i>	-.052	.221	.166	-.128	.014	-.053	.068	-.293	-.162	-.008	.914	.636	-.254	.251
	<i>P</i>	.352	.000	.003	.022	.800	.351	.227	.000	.004	.888	.000	.000	.000	.000
SSA	<i>r</i>	.028	-.119	-.070	.024	.058	.067	.153	.286	.401	.399	-.177	.184	-.136	-.106
	<i>P</i>	.622	.034	.212	.673	.301	.232	.007	.000	.000	.000	.002	.001	.016	.060
CrSVA	<i>r</i>	.019	.107	.368	-.044	.186	.125	-.121	-.147	-.230	-.093	.190	.062	-.047	.328
	<i>P</i>	.742	.057	.000	.433	.001	.026	.032	.009	.000	.098	.001	.274	.402	.000

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