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Global Sagittal Angle and T9-tilt seem to be the most clinically and functionally relevant global alignment parameters in patients with Adult Spinal Deformity

Nabil Nassim [a], Elio Mekhael [a,1], Rami El Rachkidi [a,1], Maria Saadé [a], Elma Ayoub [a], Ali Rteil [a], Elena Jaber [a], Celine Chaaya [a], Rami Rehayem [a], Julien Abi Nahed [b], Mohamad Karam [a], Ismat Ghanem [a], Abir Massaad [a], Ayman Assi [a,c,*]

[a] *Laboratory of Biomechanics and Medical Imaging, Faculty of Medicine, Saint-Joseph University of Beirut, Beirut, Lebanon*
[b] *Technology Innovation Unit, Hamad Medical Corporation, Doha, Qatar*
[c] *Institut de Biomécanique Humaine Georges Charpak, Arts et Métiers, Paris, France*

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ABSTRACT

Introduction: Radiographic analysis is necessary for the assessment and the surgical planning in adults with spinal deformity (ASD). Restoration of global alignment is key to improving patient's quality of life. However, the large number of existing global alignment parameters can be confusing for surgeons.
Research question: To determine the most clinically and functionally relevant global alignment parameters in ASD.
Material and methods: ASD and controls underwent full body biplanar X-ray to calculate global alignment parameters: odontoid to hip axis angle (OD-HA), global sagittal angle (GSA), global tilt (GT), SVA, center of auditory meatus to hip axis (CAM-HA), SSA, T1-tilt and T9-tilt. All subjects filled HRQoL questionnaires: ODI, SF-36, VAS for pain and BDI (Beck's Depression Inventory). 3D gait analysis was performed to calculate kinematic and spatio-temporal parameters. A machine learning model predicted gait parameters and HRQoL scores from global alignment parameters.
Results: 124 primary ASD and 47 controls were enrolled. T9 tilt predicted the most BDI (31%), hip flexion/extension during gait (36%), and double support time (39%). GSA predicted the most ODI (26%), thorax flexion/extension during gait (33%), and cadence (36%).
Discussion and conclusion: Among all global alignment parameters, GSA, evaluating both trunk shift and knee flexion, and T9 tilt, evaluating the shift of the center of mass, were the best predictors for most of HRQoL scores and gait kinematics. Therefore, we recommend using GSA and T9 tilt in clinical practice when evaluating ASD because they represent the most quality of life and functional kinematic of these patients.

1. Introduction

The prevalence of chronic back pain is remarkably increasing with the aging of the population and is considered to be the first cause of medical consultation (Blondel et al., 2011). Adults with spinal deformity (ASD) incidence has been reported to be up to 32% in the general population with numbers reaching 68% in elderly, thus representing a major public health issue (Schwab et al., 2005). These patients are known to have structural alterations of the spine as well as global postural malalignment (Le Huec et al., 2019) expressed by a forward shift of the trunk. In an attempt to keep the center of mass in the "conus of economy" and ensure a horizontal gaze while standing, they tend to recruit compensatory mechanisms such as pelvic retroversion and knee flexion (Barrey et al., 2011; Dubousset, 1994). In addition to the radiographic alterations, it has been reported that ASD patients showed deterioration of their quality of life (Ames et al., 2016; Schwab et al., 2003).

Spinopelvic deformities and their compensatory mechanisms are

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* Corresponding author. Laboratory of Biomechanics and Medical Imaging Faculty of Medicine, University of Saint-Joseph, Beirut, Lebanon.
E-mail address: ayman.assi@usj.edu.lb (A. Assi).

[1] the third and second authors contributed the same.

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evaluated through radiographic parameters such as: Pelvic Incidence PI (°), Pelvic Tilt PT (°), L1S1 lumbar lordosis LL (°), PI-LL mismatch (°), T1T12 thoracic kyphosis TK (°), Knee Flexion KF (°) and Coronal Cobb angle (°). Specific parameters are calculated to assess global postural alignment of the patient, such as: Sagittal Vertical Axis SVA (mm), Center of auditory meatus to hip axis CAM-HA (mm), Odontoid to hip axis angle OD-HA (°), T1 tilt (°), T9 tilt (°), Spino-sacral angle SSA (°), Global Tilt GT (°) and Global Sagittal Angle GSA (°).

While classical evaluation methods of ASD are based on radiographic analysis, as well as health-related quality of life (HRQoL) questionnaires, an interest is increasing toward a more functional evaluation during daily life activities such as walking, sitting, and climbing stairs (Kawkabani et al., 2021; Saad et al., 2022; Semaan et al., 2022; Rebeyrat et al., 2022; El Rachkidi et al., 2022). This is especially important since it has been reported that kinematic analysis of daily tasks can better predict HRQoL deterioration in ASD patients when combined to static radiographic analysis, compared to the sole use of this latter (Mekhael et al., 2023).

Therefore, clinical, radiographic and kinematic evaluation are all to be considered in this pathology. However, not all hospital and laboratory settings have access to quantitative functional analysis since it is expensive, time consuming and requires specialized technological and biomechanical knowledge.

In the current practice, radiographic analysis is still the most common method adopted by surgeons for assessment and surgical decisions in ASD patients. While the primary aim of surgical interventions in ASD is to restore global alignment that was reported to be associated with better outcomes in HRQoL (Smith et al., 2016; Lafage et al., 2021), the large number of existing postural parameters to assess global alignment in ASD can be confusing for spine surgeons.

The aim of this study was to determine which global alignment parameters are the most clinically and functionally relevant in ASD, that better predict both HRQoL scores and 3D kinematics using a machine learning approach.

2. Methods

2.1. Participants

This is an IRB-approved (CEHDF1259) prospective study including ASD and asymptomatic subjects. ASD patients above 20 years old, who complained from back pain with one or more of the following radiographic criteria: PT > 25°, SVA>50 mm, Cobb angle>20°, pelvic incidence – lumbar lordosis mismatch (PI-LL)>10° and/or T1T12 thoracic kyphosis TK > 60°. Subjects with neurological disorders, deformities in the lower limbs or presenting any other pathology (tumors, rheumatic diseases, infectious diseases, etc.) that might affect the motor function were excluded. The control group was formed by adults aged more than 20 years with no back pain and musculoskeletal disorders, as well as no history of orthopedic surgery and degenerative joint disease who accepted to participate in this study.

Demographic parameters including age, height, weight, and sex were collected.

2.2. Radiographic acquisition

All participants underwent full body biplanar X-rays (EOS imaging®, ATEC Spine Group, USA) in the free-standing position (Dubousset et al., 2005). Three-dimensional skeletal reconstructions of the spine, pelvis and lower limbs were performed by trained operators using SterEOS® software, in order to calculate the following spinopelvic, knee, and global alignment skeletal parameters (Fig. 1): Pelvic Incidence PI (°), Pelvic Tilt PT (°), L1S1 lumbar lordosis LL (°), PI-LL mismatch (°), T1T12 thoracic kyphosis TK (°), Knee Flexion KF (°), Coronal Cobb angle (°), Sagittal Vertical Axis SVA (mm), Center of auditory meatus to hip axis CAM-HA (mm), Odontoid to hip axis angle OD-HA (°), T1 tilt (°), T9 tilt (°), Spino-sacral angle SSA (°), Global Tilt GT (°), Global Sagittal Angle GSA (°) (Jackson and McManus, 1994; Amabile et al., 2016; Steffen et al., 2010; Duval-Beaupère et al., 1992; Legaye et al., 1993; Roussouly

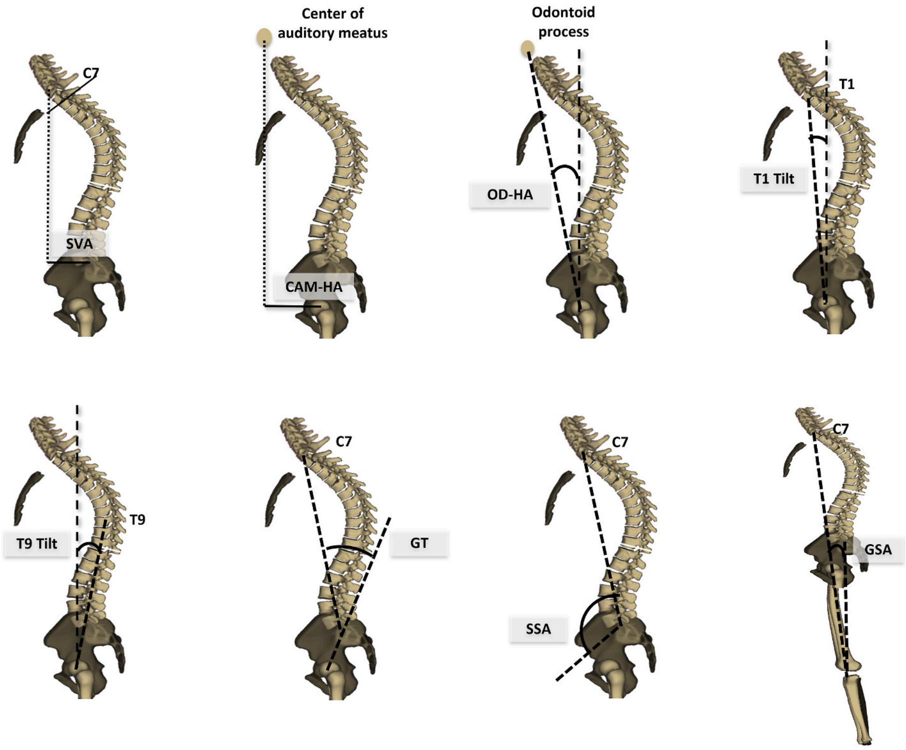


Fig. 1. 3D reconstructions of the spine based on biplanar X-rays with calculation of global alignment parameters: sagittal vertical axis SVA (mm), center of auditory meatus to hip axis CAM-HA (mm), odontoid to hip axis angle OD-HA (°), T1 tilt (°), T9 tilt (°), spino-sacral angle SSA (°), global tilt GT (°) and global sagittal angle GSA (°).

et al., 2006; Obeid et al., 2016; Diebo et al., 2016).

2.3. Quality of life questionnaires

All subjects filled out health-related quality of life (HRQoL) questionnaires including.

- Visual analog scale (VAS) to measure the severity of pain according to a score that varies between 0 and 10 and increases with severity.
- Short Form Health Survey (SF-36) including both Physical Component (PCS) and Mental Component (MCS) Summary, that varies between 0 and 100 and decreases with severity (Ware and Sherbourne, 1992).
- Oswestry Disability Index (ODI), to measure disability and quality of life impairment according to a score that varies between 0 and 100 and increases with severity (Fairbank and Pynsent, 2000).
- Beck's Depression Inventory (BDI) that varies from 0 to 63 and increases with severity (Beck et al., 1974).

2.4. Gait analysis

Eight infrared cameras (Vicon Motion Systems®, Oxford, UK) were used to capture the whole-body skeletal motion during gait. The Davis protocol was used to calculate joint and segmental kinematics of the pelvis and lower limbs with the reflective markers placed as follows (Davis et al., 1991): head, anterosuperior and posterosuperior iliac spines, distal third of the femur, lateral knee condyles, distal third of the tibia, lateral malleoli, calcaneum, and base of second metatarsal, all bilaterally. The Leardini protocol was used for the spine and trunk kinematics with the reflective markers placed as follows (Leardini et al., 2011): acromions, suprasternal notch, xiphoid process, and spinous processes of C7, T2, T10, L1, L3, and L5 vertebras. Spatio-temporal parameters (walking speed, cadence, step length, foot off, time of single and double support) as well as kinematic waveforms during the gait cycle (with the calculation of the mean and range of motion ROM) of the head, spinal segments, trunk, pelvis, and lower limbs were calculated in the 3 planes using Nexus (Vicon®, Oxford, UK). The Gait Deviation Index (GDI) was calculated for all subjects to estimate the overall gait pathology according to a normative database (varies from 0 to 100 and decreases with gait abnormalities) (Schwartz and Rozumalski, 2008).

2.5. Statistical analysis

Differences in demographics, HRQoL scores, radiographic and gait parameters, were evaluated between ASD and controls using Mann-Whitney's *U* test or Student's t-test depending on data distribution (assessed using Shapiro-Wilk's test). Sex was compared between groups using a Chi-Squared test.

A machine learning model based on random forest regression and a systematic decision tree-like approach was used to predict HRQoL scores, gait kinematics, as well as spatio-temporal parameters based on radiographic global alignment parameters. A random forest is an estimator that fits an operator-defined number of classifying decision trees on various sub-samples of the training dataset. Prediction is made by evaluating the information of the ensemble of the decision trees, to improve the accuracy of prediction and control over-fitting (Fig. 2).

Inputs for the model were the 8 radiographic global alignment parameters (SVA, CAM-HA, OD-HA, T1 tilt, T9 tilt, GT, SSA, GSA), whereas outputs were the HRQoL scores, the gait kinematic parameters and the spatio-temporal parameters that differed between ASD and controls. The number of selected trees was 500, a choice made to perform hyper-parameter optimization using a grid search technique to maximize the model's performance and prevent the risk of overfitting.

Subjects were divided randomly into 10 groups and a 10-fold cross validation was applied to ensure that every group of patients is used once for testing and 9 times for training.

The root mean squared error (RMSE) was calculated to quantify the difference between predicted and true values in each of the groups. Therefore, 10 RMSE values are obtained for each HRQoL score, gait kinematic and spatio-temporal parameter. The average of all 10 values represents the RMSE of the model for each of the outcomes (Fig. 3).

The percentage of contribution of each radiographic global alignment parameters for each output was also calculated. Two case studies were displayed to illustrate the results.

Statistical analysis was conducted using SPSS® (IBM®, New York, USA; version 2017). The level of significance was set at 0.05.

3. Results

3.1. Population

Data was collected from 124 ASD (54 ± 19 years, 93 F) and 47 control subjects (53 ± 8 years, 32 F) with similar age distribution ($p > 0.05$, Table 1).

Comparison between spinopelvic and global alignment parameters, gait kinematics and spatio-temporal parameters, as well as HRQoL scores between ASD and controls were displayed in Table 2.

In brief, ASD showed an increase in PT (19.2 ± 11.5° vs 12.5 ± 5.7°), T1T12 (53.1 ± 20.2° vs 46.8 ± 9.3°) and a decrease in L1S1 (52.3 ± 22.3° vs 61.2 ± 8.3°; all $p < 0.05$) when compared to controls. They also showed an increase in GT (22.2 ± 18.6° vs 9.3 ± 8.7°), GSA (3.6 ± 6.5° vs −1±2.2°), SVA (32.2 ± 58 mm vs-7±23.2 mm), and T9 tilt (14 ± 5.8°

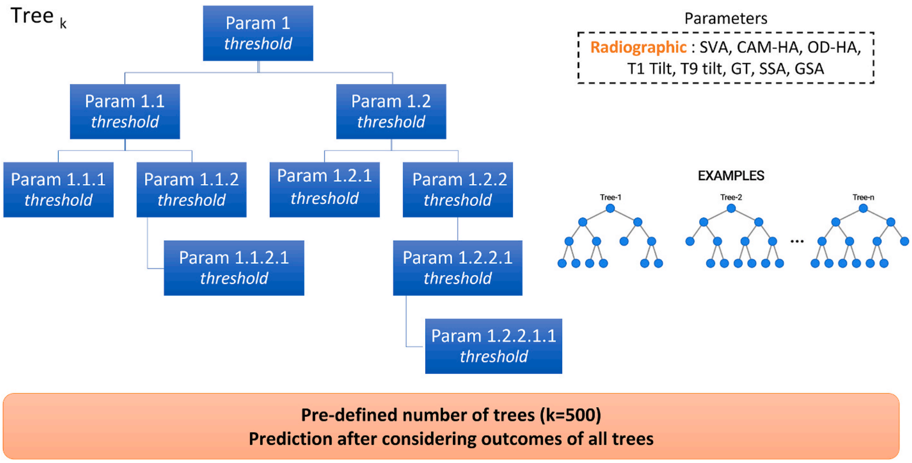


Fig. 2. Visualization of a Random Forest machine learning model.

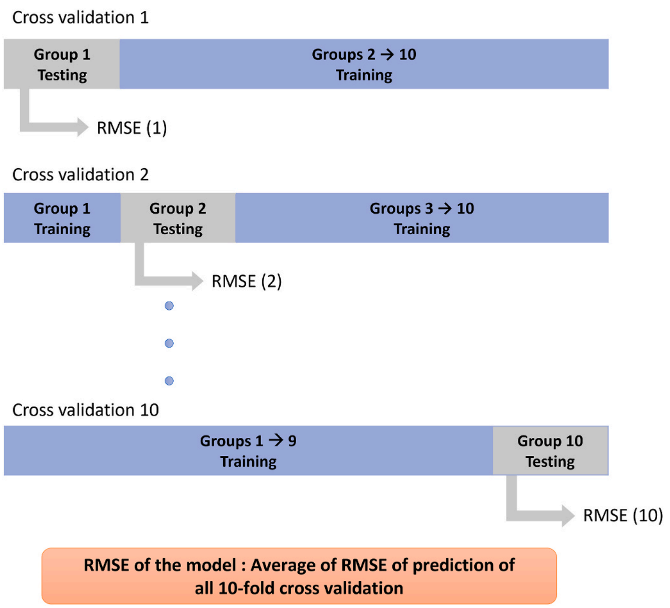


Fig. 3. Visualization of the 10-fold cross validation of the model.

Table 1
Demographic comparisons between ASD and Controls.

		ASD (n = 124)	Controls (n = 47)	p-value
Age (years)		54 ± 19	53 ± 8	0.06
Weight (Kg)		72 ± 14	73 ± 11	0.76
Height (cm)		161 ± 10	165 ± 8	**0.01**
Sex	F	93 (75%)	32 (68%)	0.36
	M	31 (25%)	15 (32%)	

vs 12.1 ± 2.4°; all $p < 0.05$) when compared to controls. ASD had a decrease in the GDI (87 ± 14.1 vs 93 ± 10.5), the mean of pelvic tilt (9.2 ± 7.9° vs 12.9 ± 6.1°), the ROM of the hip in the sagittal plane (41.8 ± 7.1° vs 45.7 ± 4.8°), and the ROM of the knee in the sagittal plane (54.5 ± 9° vs 59.6 ± 6.2°; all $p < 0.05$) when compared to controls. ASD had a decreased walking speed (0.6 ± 0.1 m/s vs 0.7 ± 0.1 m/s) and step length (0.3 ± 0.06m vs 0.4 ± 0.04m; all $p < 0.05$). They also had a decreased PCS (39 ± 9 vs 50 ± 8) and an increased ODI (32 ± 19 vs 15 ± 6; all $p < 0.05$).

3.2. Machine learning model results

3.2.1. Root mean squared error (RMSE) calculation

When radiographic global alignment parameters were given to predict HRQoL scores, RMSE varied between 0.6 ± 0.2 for VAS for pain and 3.6 ± 0.9 for ODI (Table 3).

When radiographic global alignment parameters were given to predict gait kinematics, RMSE varied between 0.3 ± 0.1° for the ROM of the thorax in the sagittal plane and 2.9 ± 0.6 for the GDI (Table 3).

When radiographic global alignment parameters were given to predict spatio-temporal parameters, RMSE varied between 0.02 ± 0.01m for step length and 2.9 ± 0.6 steps/min for cadence (Table 3).

3.2.2. Percentage of contribution for prediction

T9 predicted the most the following HRQoL scores and kinematic parameters: MCS (20%), VAS for pain (23%), BDI (31%), the ROM of pelvic tilt (21%), the mean of pelvic tilt (33%), the mean of hip flexion/extension (36%), and the double support time (39%).

GSA predicted the most the following HRQoL scores and kinematic parameters: ODI (26%), the ROM of knee flexion/extension (31%), the ROM of thorax flexion/extension (33%), walking speed (27%), step length (29%), and cadence (36%).

Table 2
Radiographic spinopelvic parameters, global alignment parameters, gait kinematics, spatio-temporal parameters, and HRQoL scores: comparisons between ASD and Controls.

		ASD		Controls		p-value
		Mean	SD	Mean	SD	
Radiographic spinopelvic	PT (°)	19.4	11.5	12.5	5.7	**<0.001**
	T4T12 (°)	48.9	20.6	41.7	8.9	**0.001**
	T1T12 (°)	53.1	20.2	46.8	9.3	**0.005**
	Cobb angle (°)	21.1	18.5	3.5	5.4	**<0.001**
	PI-LL (°)	0.18	21.5	−11.0	8.9	**<0.001**
	PI (°)	52.5	11.5	50.2	11.3	0.25
	L1S1 (°)	52.3	22.3	61.2	8.3	**<0.001**
Radiographic global alignment	GT (°)	22.2	18.6	9.3	8.7	**<0.001**
	ODHA (°)	4.3	3.6	3.1	1.9	0.09
	GSA (°)	3.6	6.5	−1.0	2.2	**<0.001**
	SVA (mm)	32.2	58.0	−7.0	23.2	**<0.001**
	CAM HA (mm)	10.7	58.8	−27.4	29.8	**<0.001**
	SSA (°)	120.2	17.5	131.0	7.1	**<0.001**
	T1 Tilt (°)	2.8	5.9	5.3	2.5	**0.04**
	T9 Tilt (°)	14.0	5.8	12.1	2.4	**0.04**
Gait kinematics	GDI	87.0	14.1	93.0	10.5	**0.003**
	Mean Thorax Flexion/ Extension (°)	8.3	11.8	3.9	4.6	0.11
	ROM Thorax Flexion/ Extension (°)	3.2	1.3	3.2	1.2	0.69
	Mean Pelvic Tilt (°)	9.2	7.9	12.9	6.1	**0.005**
	ROM Pelvic Tilt (°)	3.8	1.6	3.8	1.4	0.97
	Mean Hip Flexion/ Extension (°)	15.6	9.9	18.3	7.5	0.10
	ROM Hip Flexion/ Extension (°)	41.8	7.1	45.7	4.8	**0.002**
	Mean Knee Flexion/ Extension (°)	21.9	6.1	21.4	4.7	0.59
	ROM Knee Flexion/ Extension (°)	54.5	9.0	59.6	6.2	**0.001**
Spatio-temporal	Walking Speed (m/s)	0.6	0.1	0.7	0.1	**<0.001**
	Cadence (steps/min)	63.5	8.5	69.2	9.8	**<0.001**
	Step Length (m)	0.3	0.06	0.4	0.04	**<0.001**
	Double Support (s)	0.2	0.11	0.14	0.06	**<0.001**
HRQoL scores	SF36-PCS	39	9	50	8	**<0.001**
	SF36-MCS	50	9	54	7	**0.009**
	VAS for pain	6	3	3	2	**<0.001**
	ODI	32	19	15	6	**<0.001**
	BDI	11	8	6	3	**<0.001**

GT predicted for the most the following kinematic parameters: the mean of knee flexion/extension (20%), the GDI (23%), and the mean of thorax flexion/extension (25%).

CAM-HA predicted the most the following kinematic parameter: the ROM of hip flexion/extension (35%).

SVA predicted the most the following HRQoL score: PCS (19%).

OD-HA, SSA and T1 tilt predicted all HRQoL scores and kinematic parameters with poor percentage of contribution.

The percentage of contribution to predict each of the outputs by each input is displayed in Figs. 4–6.

Table 3
Root mean square error (RMSE) of predictions of HRQoL, gait kinematics, and spatiotemporal parameters.

		RMSE	SD
HRQoL scores	SF36-PCS	2.0	0.5
	SF36-MCS	2.0	0.4
	VAS for pain	0.6	0.2
	ODI	3.6	0.9
	BDI	1.8	0.7
Gait kinematics	GDI	2.9	0.6
	Mean Thorax Flexion/Extension (°)	1.6	1.0
	ROM Thorax Flexion/Extension (°)	0.3	0.1
	Mean Pelvic Tilt (°)	1.6	0.5
	ROM Pelvic Tilt (°)	0.4	0.1
	Mean Hip Flexion/Extension (°)	2.2	0.8
	ROM Hip Flexion/Extension (°)	1.5	0.3
	Mean Knee Flexion/Extension (°)	1.4	0.2
	ROM Knee Flexion/Extension (°)	1.8	0.4
Spatio-temporal	Walking Speed (m/s)	0.05	0.01
	Cadence (steps/min)	2.90	0.60
	Step Length (m)	0.02	0.01
	Double Support (s)	0.03	0.01

3.3. *Case study*

Two examples of patients with ASD are presented in Fig. 7. On static X-rays, patient 1 had higher GSA (5° vs −11°), T9 tilt (18° vs 12°) and lower SVA (29 mm vs 119 mm), CAM-HA (3 mm vs 53 mm), GT (30° vs 42°) and ODHA (0.8° vs 6°) compared to patient 2. During gait, patient 1 had lower GDI (62 vs 84), mean of pelvic tilt (−0.4° vs 13°), ROM of hip flexion/extension (35° vs 45°) and higher double support time (0.3s vs 0.2s) compared to patient 2. On the HRQoL scores, patient 1 had lower MCS (29 vs 56) and higher PCS (34 vs 30), VAS for pain (10 vs 3), ODI (48 vs 40) and BDI (17 vs 3).

4. Discussion

The main purpose of the corrective surgery in ASD is to restore the global alignment in an attempt to improve quality of life of these patients (Smith et al., 2016; Lafage et al., 2021). A multitude of radiographic global alignment parameters exist in the literature. The aim of this study was to define which global alignment parameter is the most relevant both clinically and functionally using a machine learning approach. This study showed that the Global Sagittal Angle (GSA) and T9 tilt were the most relevant to predict 3D kinematic parameters and HRQoL scores in ASD patients.

While the SVA (Sagittal Vertical Axis) is the most commonly used parameter to assess global alignment, it has been shown that it was only the main predictor of PCS, with poor results when predicting kinematic parameters. This is probably due to the fact that this parameter does not represent a global view of the patient's alignment. In fact, it does not take into consideration the cervical segment, as well as the hip and lower limbs. Moreover, the SVA requires a calibration since it is a millimetric measure and does not take into consideration the patient's height in the evaluation of global malalignment. It is known that the compensation mechanisms in ASD during walking occur not only in the thoracic segment of the spine, but also on the pelvis and lower limbs levels with increased hip and knee flexion and a decreased mobility of these segments (Semaan et al., 2022). This explains the relatively poor contribution of the SVA in the prediction of kinematic parameters.

Furthermore, OD-HA (Odontoid to Hip Axis angle), SSA (Spino-Sacral Angle) and T1 tilt contributed poorly to the prediction of all HRQoL scores and kinematic parameters. This may be related to the fact that all these angles do not evaluate the kyphosis at the lower segment of the thoracic spine in ASD. In fact, evaluation of this segment is essential since the compensation mechanisms in ASD first occur at the proximal adjacent segment to the primary lumbar degeneration (Barrey et al., 2011). Moreover, similarly to the SVA, these parameters do not take into consideration the lower limbs.

CAM-HA (Center of Auditory Meatus to Hip Axis distance) was only the main predictor of the ROM of the hip in the sagittal plane. This might be explained by the fact that this angle takes into consideration the hip position (Steffen et al., 2010). However, it was not able to largely contribute to the prediction of other kinematic parameters as well as HRQoL scores. Similarly to the previous parameters, it does not take into account the segmental compensation that occurs in the spine. It is also a millimetric measurement that varies with patient's height. The fact that these parameters poorly predict HRQoL scores is also in accordance with recent studies in the literature that showed weak correlations between pain and sagittal plane radiographic parameters (Kieser et al., 2022), while previous studies showed divergent results (Schwab et al., 2003, 2005).

GT (Global Tilt) was the main predictor of the following kinematic

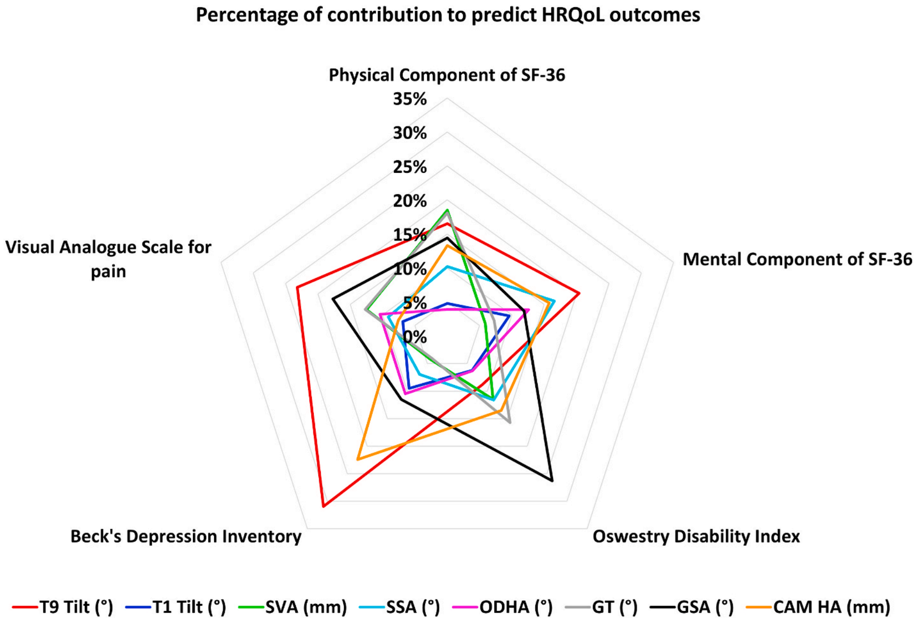


Fig. 4. Percentage of contribution to predict Health-Related Quality of Life scores among global alignment parameters.

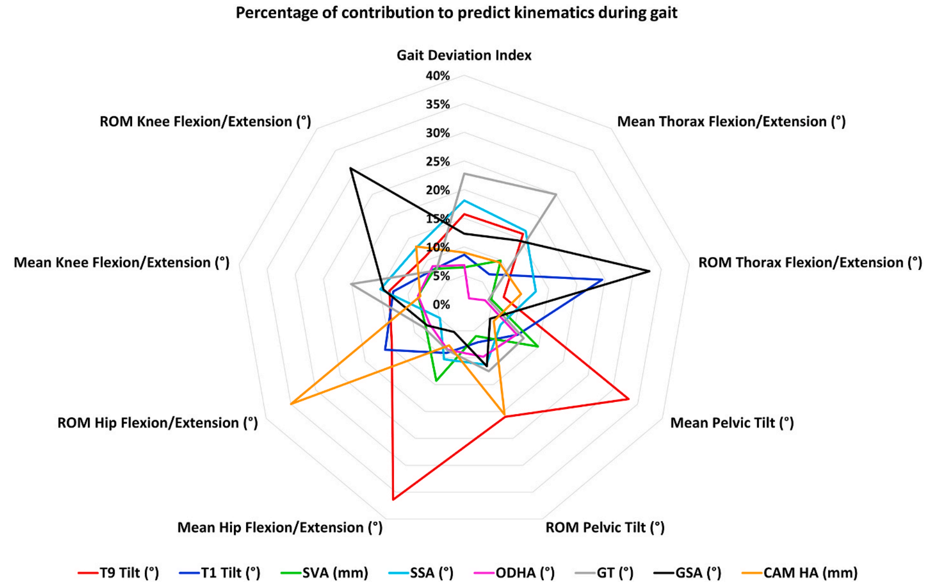


Fig. 5. Percentage of contribution to predict gait kinematics among global alignment parameters.

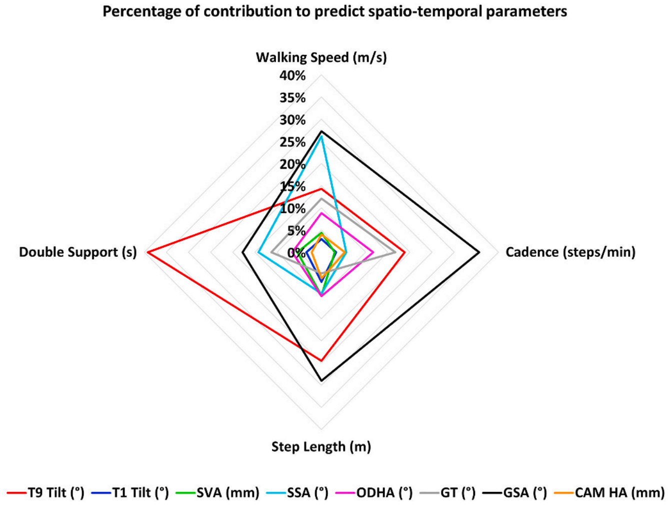


Fig. 6. Percentage of contribution to predict spatio-temporal parameters among global alignment parameters.

parameters: the GDI (Gait Deviation Index), the mean of the knee and the thorax in the sagittal plane. This parameter was able to predict kinematic parameters better than the previous parameters, since it takes into consideration both the sacral and femoral head positions (Obeid et al., 2016). However, similarly to the previous parameters, GT does not account for the lower segment of the thoracic spine. This is why the use of this parameter alone might not be enough when assessing ASD patients.

Interestingly, T9 tilt was the main predictor for the mental component summary of SF-36, VAS for pain, BDI, the mean of the hip and pelvis in the sagittal plane as well as the ROM of the pelvis in the sagittal plane and the double support time. The ability of T9 tilt to be the best predictor for most HRQoL scores and kinematic parameters was expected, since this angle evaluates the shift of the center of mass, which is key to assess patient's balance (Legaye et al., 1993; Vialle et al., 2005). Similarly to the GT, T9 tilt also takes into consideration the femoral head position. However, T9 tilt might be more relevant since it accounts for the compensation mechanisms that occur at the transition between the upper and the lower segments of the thoracic spine. This is a key factor, since the fixation of the T9 vertebra is associated with a high risk of proximal junctional kyphosis (PJK) following surgery (Yasuda et al., 2017). Thus, taking into consideration the T9 tilt when evaluating ASD is essential because it predicts the most HRQoL scores and kinematic parameters, while being associated with surgical complications.

Moreover, GSA (Global Sagittal Angle) was the main predictor for ODI, the ROM of the thorax and knee in the sagittal plane as well as step length, walking speed and cadence. Alongside T9 tilt, GSA was also able to predict the most HRQoL scores and kinematic parameters. This was expected, since this angle evaluates both the trunk shift and knee flexion (Diebo et al., 2016). As previously discussed, evaluating compensations occurring at the lower limbs level is essential in ASD (Semaan et al., 2022). Furthermore, GSA was previously shown to be strongly correlated with all spinal, pelvic, lower-extremity sagittal parameters and patient-reported clinical scores (Diebo et al., 2016). Consequently, it is important to couple GSA with T9 tilt since they give a more complementary evaluation of the global alignment in ASD by assessing the spine, the hips and the knee while taking into consideration the center of mass. These angles are not affected by patients' anthropometric measurements and do not require calibration.

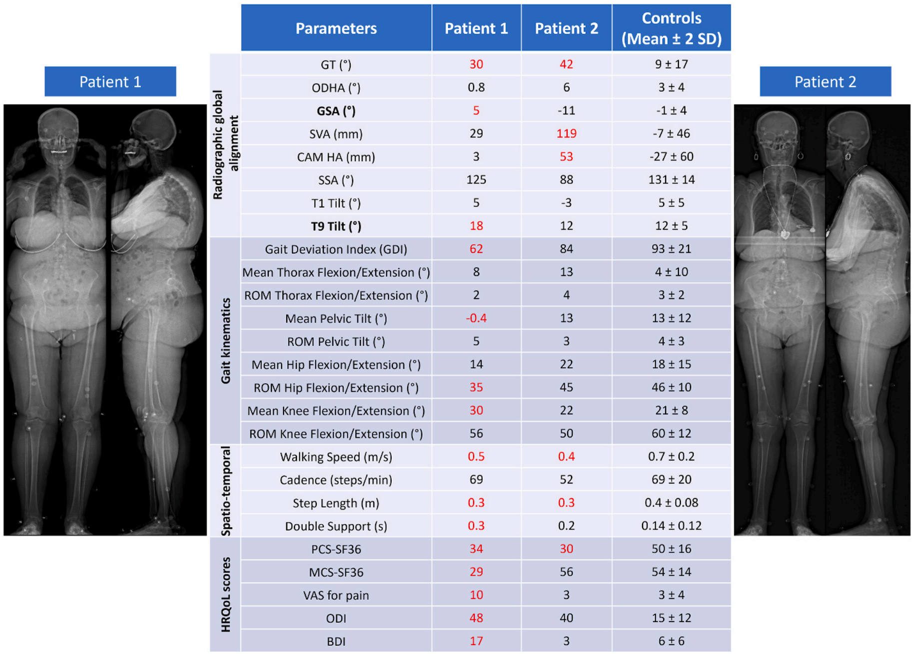
The results in this study were also illustrated by the case study where patient 1, who had higher GSA and T9 tilt and lower SVA compared to patient 2, had more deterioration in all HRQoL scores except the PCS which has been shown to be better predicted by SVA. Moreover, patient 1 had more deterioration in the kinematic parameters compared to patient 2. Relying solely on SVA would have made patient 2 more affected by the spinal deformity.

The main limitation of this research was the lack of consideration of comorbidities that could impact the prediction of HRQoL scores, making them a confounding variable.

The use of machine learning technique in this study could have been replaced by multiple regressions. We obtained similar results when using a multiple linear regression model. However, treatment decision making, and surgical planning are based on algorithms that the clinician follows. This reasoning is very similar to that of a decision tree, which has led us to adopt a random forest model instead of other statistical or machine learning methods.

5. Conclusion

In the current healthcare context, considering patients' function is essential during clinical evaluation (Mekhael et al., 2023). Therefore, it



	Parameters	Patient 1	Patient 2	Controls (Mean ± 2 SD)
Radiographic global alignment	GT (°)	30	42	9 ± 17
	ODHA (°)	0.8	6	3 ± 4
	GSA (°)	5	-11	-1 ± 4
	SVA (mm)	29	119	-7 ± 46
	CAM HA (mm)	3	53	-27 ± 60
	SSA (°)	125	88	131 ± 14
	T1 Tilt (°)	5	-3	5 ± 5
	T9 Tilt (°)	18	12	12 ± 5
Gait kinematics	Gait Deviation Index (GDI)	62	84	93 ± 21
	Mean Thorax Flexion/Extension (°)	8	13	4 ± 10
	ROM Thorax Flexion/Extension (°)	2	4	3 ± 2
	Mean Pelvic Tilt (°)	-0.4	13	13 ± 12
	ROM Pelvic Tilt (°)	5	3	4 ± 3
	Mean Hip Flexion/Extension (°)	14	22	18 ± 15
	ROM Hip Flexion/Extension (°)	35	45	46 ± 10
	Mean Knee Flexion/Extension (°)	30	22	21 ± 8
	ROM Knee Flexion/Extension (°)	56	50	60 ± 12
Spatio-temporal	Walking Speed (m/s)	0.5	0.4	0.7 ± 0.2
	Cadence (steps/min)	69	52	69 ± 20
	Step Length (m)	0.3	0.3	0.4 ± 0.08
	Double Support (s)	0.3	0.2	0.14 ± 0.12
HRQoL scores	PCS-SF36	34	30	50 ± 16
	MCS-SF36	29	56	54 ± 14
	VAS for pain	10	3	3 ± 4
	ODI	48	40	15 ± 12
	BDI	17	3	6 ± 6

Fig. 7. Example of two patients with ASD.

is important that the static radiographic parameters used for clinical decision making not only reflect patient's quality of life but also account for their kinematic limitations. This study showed that among all global alignment parameters, GSA, evaluating both trunk shift and knee flexion, and T9 tilt, evaluating the shift of the center of mass, contribute the most in the prediction of clinical and functional deteriorations in ASD patients. Therefore, we recommend using GSA and T9 tilt in clinical practice when evaluating ASD because they represent the most quality of life and functional kinematic of these patients.

Declaration of competing interest

None.

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