From Generic to the Patient Specific 3D Model of the Spine in Case of Adolescent Idiopathic Scoliosis (AIS)

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ABSTRACT

This research is focused on a development of the system for noninvasive assessment of scoliosis based on generic 3D model of the spine and 3D dorsal surface of the patient. Since scoliosis is very complex condition that affects 6-8% of world population, and the most vulnerable group belongs to adolescent age, the need for reducing the number of required expositions of patients to radiological examinations, or complete elimination of such methods, in clinical practice appears as particularly important. The tendency is to direct diagnostics towards assessing the deformity on the basis of external indicators, functionality and quality of life of patients. All this enables the creation of a framework for a systematic review and analysis of a wide range of measures and parameters of deformities, with both internal and external parameters of the manifestation, and with generation of a so-called index of scoliosis. We developed the system for early detection and estimation of scoliosis curves and other deformity parameters based on parametric and scalable 3D model of the spine which is reconstructed from series of CT slices and which is capable for registering with dorsal optical scans of the patients in standing position. The methodology is implemented using Visual Basic Application (VBA) macros in a CAD environment to study relationship between dorsal and internal parameters of spinal deformities and to generate 3D visualization – “patient specific” models.

Keywords: Adolescent Idiopathic Scoliosis (AIS), Non-invasive diagnosis, 3D patient- specific deformity models

1. INTRODUCTION

Scoliosis, is the most common spinal disorder in children and adolescents, can be characterized by a side-to-side curvature of the spine, usually with a rotation of vertebrae and often a reduced kyphosis in thoracic curves [1]. Adolescent idiopathic scoliosis (AIS) accounts for approximately 90 % of cases of idiopathic scoliosis in children. Although statistics for the whole of the EU are not available, in the US 1.26 million patients had health care for spinal deformity in 2004. Approximately 134,500 patients with spinal deformity were hospitalized and 93% of hospitalized patients were diagnosed with scoliosis. Some reports show that the prevalence of scoliosis is increasing as the population ages, estimating that up to 70% of the population aged over 60 currently has mild to severe spinal curves. However, scoliosis is mostly interesting in early stages especially in adolescent period that are developed without any external or internal factors. This type of scoliosis are generally signed as idiopathic scoliosis [2]. Another types include congenital scoliosis developed by abnormal development of vertebra, infantile, juvenile, etc. Scoliosis in clinical praxis may be treated on several ways. Smaller curves (up to 10 degrees according to Cobb method) should be monitored in certain period of patient growth. Moderate curves up to 30 degrees may be treated by physiological therapy and exercises, and over 40 degrees by braces, specially designed for patients. Curves above 50 degrees can cause severe pain and problem in breathing and big aesthetic changes, are usually treated by surgery [3].

1.1 TRADITIONAL DIAGNOSIS

Traditionally scoliosis is diagnosed in a static position and is carried out by visual examination or through the PA/AP radiographic images and by descriptive and quantitative indicators of the deformity measured by physicians. In some cases diagnosis relies on reading X-ray, and in some cases using MRI/CT. It is known that neither CT nor MRI, do not give a picture of the patient in a standing position, and as the most reliable diagnosis of the deformities suitable for patients and praxis is stereo radiography (e.g. The system EOS) [5], [6], [7].

In clinical praxis, the „gold standard“ for scoliosis assessment is Cobb-Ferguson's method based on x-ray films [4], [5]. This method is manual and requires experienced physicians to find complementary angles between specific reference lines on films (Fig.1).

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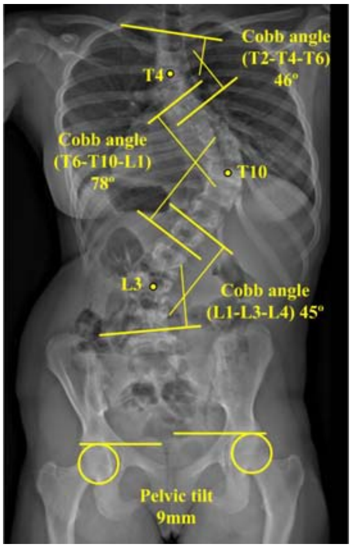

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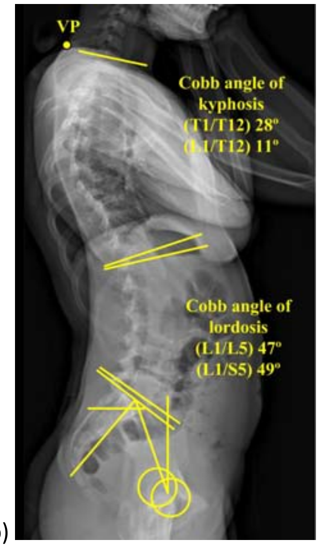


Figure 1: Analysis of the deformity on x-ray films – Cobb method a) frontal b) sagittal plane

Advances in technical development of modern optical scanning systems offer multiple options to design non-invasive, accurate and faster diagnostic methods. Those methods are based on morphometric characteristics of anatomical deformity, functionality, and quality of life of the patients suffering from adolescent idiopathic scoliosis.

2. NEW NON-INVASIVE 3D DIAGNOSIS

We proposed a non-invasive 3D methodology and the system to quantify deformity measures using patient-specific models generated from patient's dorsal shape, anatomical landmarks, curve of surface asymmetry, and middle spinal curve generated from optical scan data. Developed system is created using knowledgeware technology and VBA macros implemented in PLM system CATIA to perform these measurements with minimal human intervention and repeatedly. General methodology for obtaining a patient specific 3D model of the deformity is given on the Fig.2.

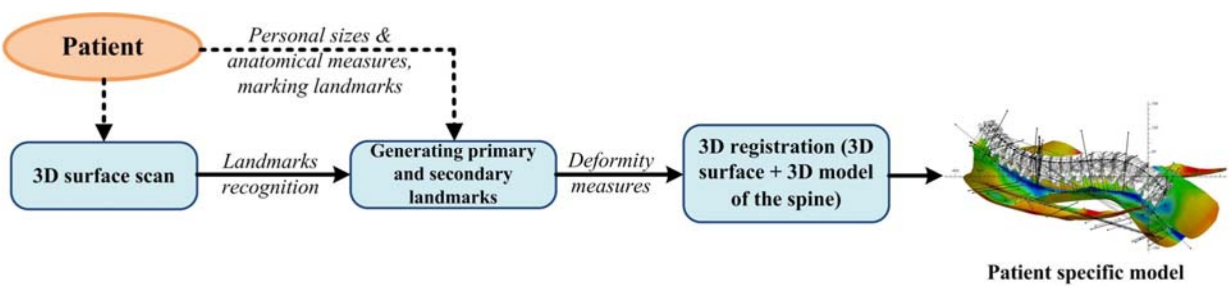


Figure 2: Stages of generating a 3D model of the deformity – patient specific model

2.1 MATERIALS AND METHODS

In order to obtain patient – specific model of spinal deformity and its evaluation we used the following datasets, materials and methods in this research:

- Patient datasets;
- 3D scanning and reconstruction of the dorsal surface;
- 3D spinal reconstruction – Generic 3D spinal model;
- Surface importing and analysis in PLM system CATIA, and curvature analysis of the dorsal surface;
- Application of Knowledgeware technologies and macros:

- extracting dorsal asymmetry line, middle spinal line, and curvature analysis of those lines in 3 planes – 3D analysis of the spinal deformity;
  - creating reference elements for vertebral models orientation towards the dorsal surfaces;
  - mathematical measurements of deformity indicators (internal and external);
  - 3D visualization of the deformity model, apical vertebrae and primary and secondary curve detection.
- Reports on 3D analysis and visualizations and statistical analysis.

2.1.1 Patient data

In our database we had 495 patients with different types of spinal deformities (290 female patients (58.6%) and 205 male patients (41.4%)) with valid optical scans of dorsal surfaces recorded at first visit from 2008. to 2013. Target group in this research were 372 adolescent patients with idiopathic scoliosis (141 male patients (28.5%) and 231 female patients (46.7%)).

2.1.2 3D Dorsal Surface Acquisition – Rasterstereography method

The acquisition of point clouds is done using active stereo-visual sensor with structural light. The sensor projects a bundle of light into horizontal lines (stripes) on the dorsal surface of the patient using in ratio 1:1. Since the transmission projector is positioned in the direction of the surface, there is no occlusion of visibility, that the camera can cover all areas of the surface [6]. The most important anatomical characteristics are automatically detected [7] and preparation of patients is not necessary as well as labelling markers (Marker-less diagnosis). As the output from the scanning process *.txt files containing coordinates of the cloud data points and markers in the form of ASCII coordinates (x, y, z) are generated.

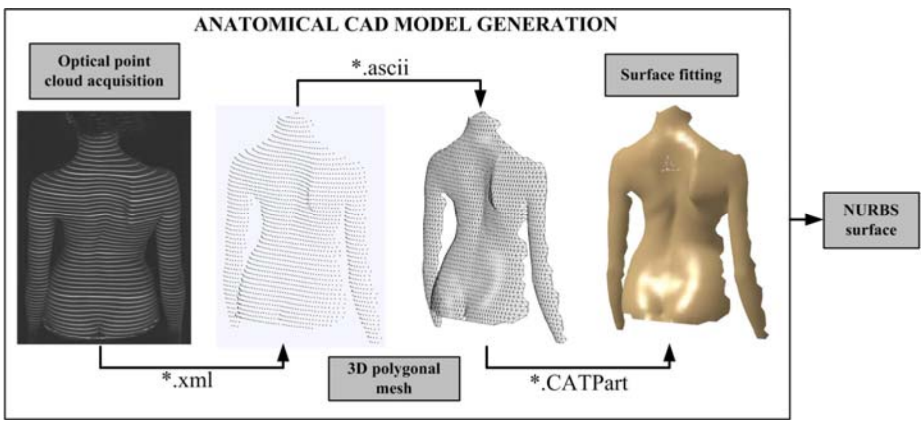


Figure 3: Stages of 3D reconstruction of the dorsal surface: Acquisition, Cloud of points, Mesh, Surface

We obtained 3D reconstruction of the point cloud data from scanning the back surface of patients through to several characteristic stages (see Fig. 3). Reconstruction process from point clouds to polygonal models we performed in Geomagic Studio (333 Three D Systems Circle, Rock Hill, SC 29730, USA). After the last phase of reconstruction we obtained NURBS surface that fully represents the true shape of the dorsal surface of the patient.

2.1.3 3D reconstruction of the spine in Materialise MIMICS

In this research we applied semiautomatic segmentation algorithms TH (Tresholding) and RG (Region Growing) for generating axial contours on the series of CT slices in Mimics Base 18.00 software (Materialise NV, Technologielaan 15, 3001 Leuven, Belgium), [8], [9], [10]. 3D reconstruction of all vertebral parts is performed on the dataset: 461 DICOM/CT slices, CT device PHILIPS/MX800 IDT16, voxel resolution 0.7188×0.7188×1.5mm.

2.1.3.1 Vertebral segmentation, 2D contours and 3D masks

After isolating bone structures using TH values for bones, and due to very complex contacts between vertebrae e.g. intervertebral discs and its facet joints (lat. „Facies Articularis Inferior“ and „Facies Articularis

Superior"), we performed segmentation in axial and PA/AP planes. We also excluded intervertebral discs and spinal canal structures and ligaments from bone structures.

After segmentation we generated external 2D contours in each slice and grouped them in segmentation masks for every lumbar, thoracic and cervical vertebrae using regional growing – RG algorithm [11]. Segmentation 3D masks represent very complex shapes of the vertebra (vertebral bodies, pedicles, spinal processus, facets, etc.) and initiate next stage of 3D reconstruction (Fig.4).

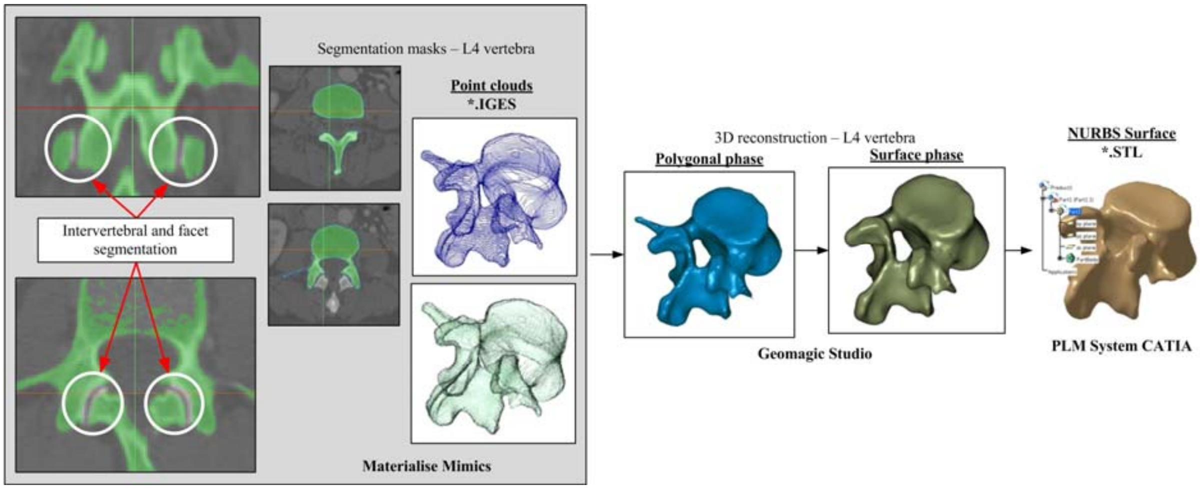


Figure 4: 3D reconstruction of the 4th lumbar vertebra from segmentation masks (point clouds) to 3d NURBS model

We used Geomagic Studio (333 Three D Systems Circle, Rock Hill, SC 29730, USA) to process polygonal meshes and to create NURBS surfaces of each vertebra. After final 3D reconstruction of all vertebral groups we created 3D assembly of the spine – generic 3D phantom.

2.1.4 Generic 3D spinal model

PLM system CATIA® (Dassault Systèmes, France) [12] allowed us to create scalable kinematic model that represents ideal (physiologically normal) spine without deformities (Fig.5a). This model is registerable to the dorsal scans of all variety of sizes and weight of patients with spinal deformities (Fig.5b).

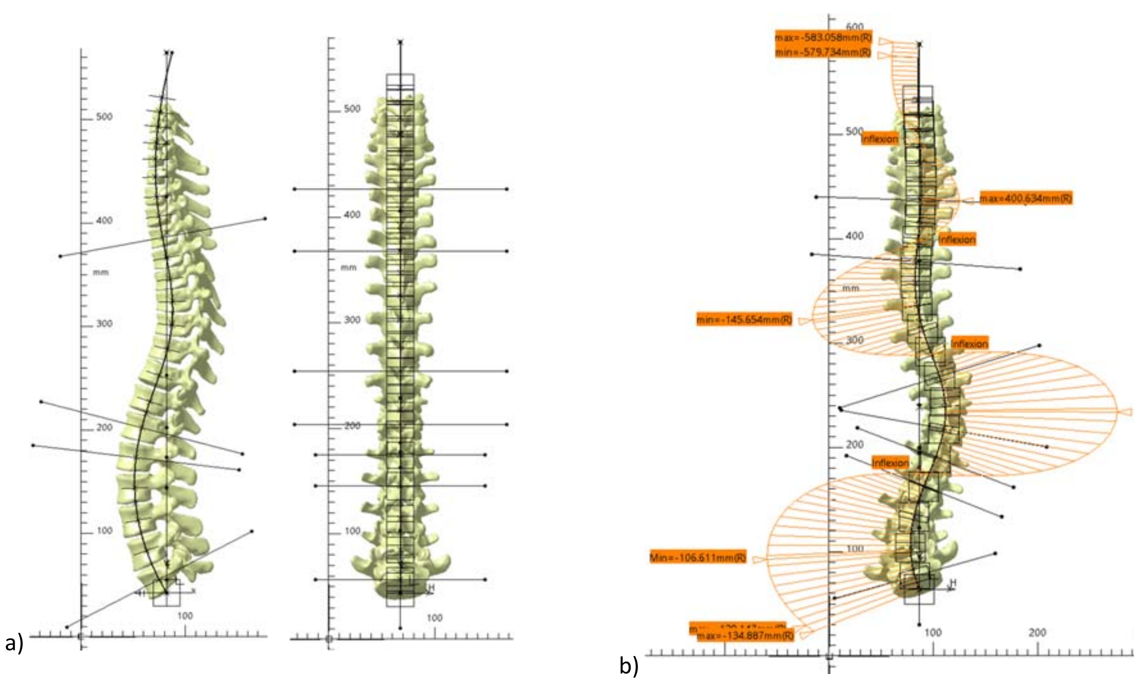


Figure 5: Generic 3D Spine, a) physiologically normal spine in sagittal and frontal plane, b) scoliotic spine and its curvature analysis

This model is adaptable to different types of non-congenital spinal deformities (kyphosis, lordosis and scoliosis) and different sizes and shapes of back patient's surface. Scaling factor is calculated based on length of the B-Spline segment of the middle spinal line and its relation to the key anatomical landmarks of the dorsal surface. This model also allows further geometrical analysis, locally in each point of the representative spinal line [3] or globally (extracting inflection points for Cobb angle references in sagittal and frontal planes, etc.).

2.2 KNOWLEDGEWARE TECHNOLOGIES

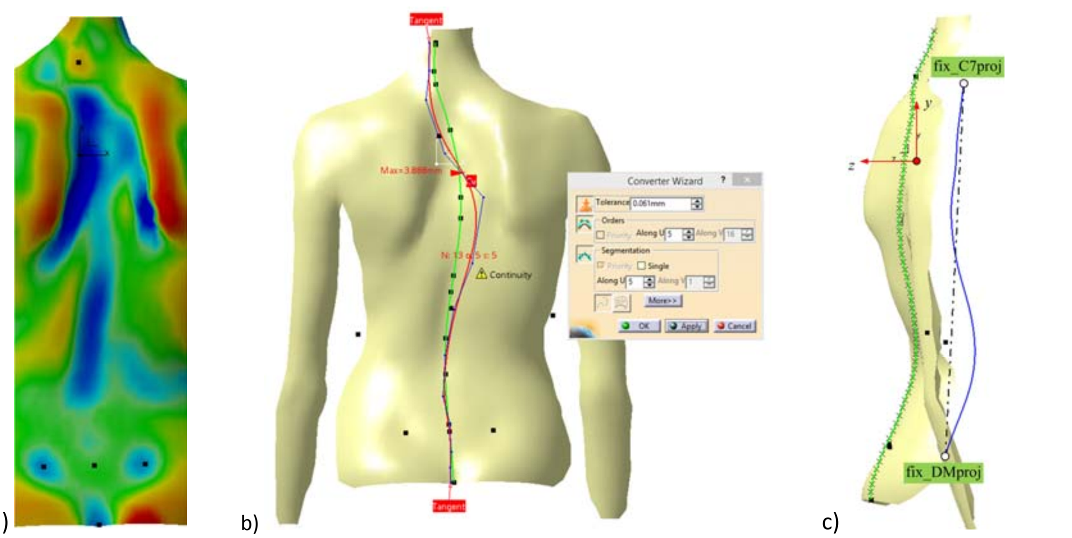
We employed PLM system CATIA V5R20 to automate the methodology with in-built VBA scripts environment and developed a macro *ScoliosisSimulator-3DSpinalRegistration.catvba* [13]. This macro takes the patient's optical scan data of dorsal surface. It generates elements of CAD skeletal model based on a generic parameterized CAD 3D model of spine (by rigid registration) and generates key parameters to quantify deformity [14], [15].

We implemented VBA macro for generating and visualizing reference elements of 3D skeletal model on the spinal curve. For this purpose we used Turner-Smith's rule, which localize peaks of spinal processus on the dorsal surface. The VBA macro produces a set of diagnostic parameters exported in separate *.xls file for further analysis.

2.2.1 Anathomical landmarks, middle spinal line and asymmetry dorsal line

The process starts with the generating of a dorsal symmetry line and central spinal line. The central line of the dorsal surface is represented by a set of focal points of the transversal profiles generated during the scan. This line can be single, double or triple depending on the degree of deformity, and in ideal cases coincides with the line of spinal processes. In addition to anatomical landmarks visible on patient skin e.g. C7 („Vertebral Prominens – VP"), SIPS (DL/DR -„Spina Iliaca Posetrior Superior"), and sacral point (S), this line is considered as the most important for description of the external indicators of deformities and for establishing correlations with internal ones [16].

The points of the central spinal line are generated based on the shape of the central symmetry line and on orientation of the vector of surface normal in the proximity of focal points. Interpolation of the focal points generates the initial central spinal line that runs through the centroids of all vertebral bodies, but geometrically is unfavorable due to numerous inflection points.



a) b) c)

Figure 6: Dorsal surface analysis a) anatomical landmarks, b) approximation of middle spinal line with 5th degree B-spline c) sagittal spinal segment of B-Spline curve

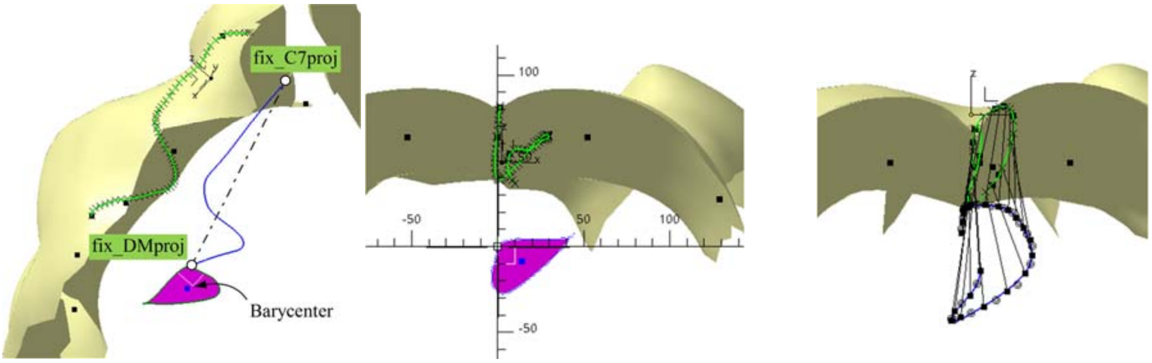
Having in mind that the majority of deformities occur between vertebrae L5-C7, the initial central spinal line is the basis for creating a smooth (approximated) line segment in which are centroids of vertebral bodies distributed (Fig.6). Approximation of the central spinal line is performed by B-spline function [17]. Based on the length of the approximated line segment, the scaling factor of vertebrae is determined. Knowing the line of symmetry of the dorsal surface additional markers can be determined and can detect the spinous extensions -

processes, the peaks of the curves and transition points of the lumbar-thoracic and cervical-thoracic curve. Based on these, the measurement of linear and angular anatomical measures of the dorsal surface is provided. Among the characteristic ones are the external parameters of the body length, the angles of body inclination, the tilt of the pelvis, body imbalance, cervical and lumbar flexion, and kyphosis and lordosis angles.

2.2.2 Barycenter of the middle spinal line and axial rotations of each vertebra

Developed system enables the detection and monitoring of several internal parameters of spinal deformity. Of particular importance are the scaling factor, Cobb's angles and other angles according to SOSORT recommendations in the frontal and sagittal plane, and axial rotation of the vertebrae in the transversal plane, as well as external measures.

Position of the barycenter is obtained by projecting the central line of the spine on the plane perpendicular to the local spinal axis and the center of gravity calculation (Fig.7a). According to the position of the barycenter, we can draw a conclusion about the specific type of deformity: Figure 7a shows anterior anisophasic dextroconvex scoliosis (front, right).



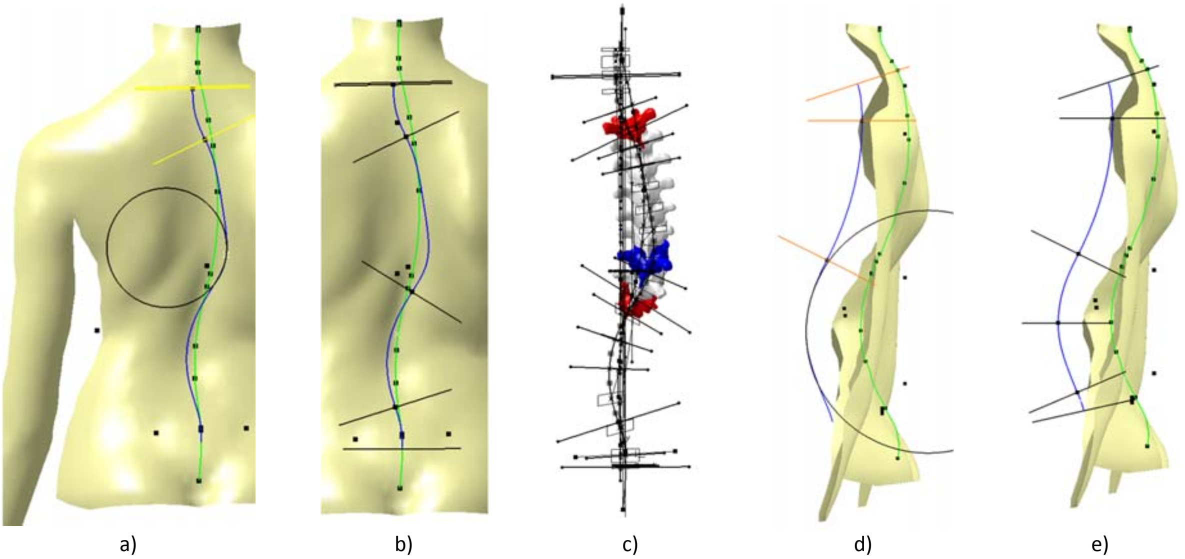
a) b)

Figure 7: Spinal segment from fixed markers DM to C7 a) position of the barycenter, b) reference lines of axial vertebral rotations

Absolute axial rotations of each vertebra in transversal plane are: AxialRotL5; AxialRotL4; AxialRotL3; AxialRotL2; AxialRotL1; AxialRotT12; AxialRotT11; AxialRotT10; AxialRotT9; AxialRotT8; AxialRotT7; AxialRotT6; AxialRotT5; AxialRotT4; AxialRotT3; AxialRotT2; AxialRotT1; AxialRotC7; AxialRotC6; AxialRotC5 (Fig.7b).

2.2.3 Spinal curvature analysis in frontal and sagittal planes

By sliding osculating circle along the smooth projection of the middle spinal line in frontal plane system generates inflection points and Cobb reference lines (Fig.8a and Fig.8b).



a) b) c) d) e)

Figure 8: Analysis of the middle spinal line projections a) frontal curvature analysis, b) inflection points extraction in frontal plane, c) primary curve, d) sagittal curvature analysis, e) inflection points extraction in sagittal plane

Inflection points are automatically generated on the places where curve changes its curvature, due to zero value of second derivatives. In concrete case, system generated 6 inflection points and 6 reference lines in frontal plane. Similar analysis is done in sagittal plane (Fig.8d and Fig.8e). Based on reference lines, system generates following Cobb angles (Cobb-XY0, Cobb-XY1, Cobb-XY2, Cobb-XY3, Cobb-XY3; Cobb-YZ0, Cobb-YZ1, Cobb-YZ2, Cobb-YZ3, Cobb-YZ4). Number of generated Cobb angles depends on degree of B-Spline that represents middle spinal line, or by the number of the extracted inflection points. In this research our focus is directed towards curves greater than 10º, primary (Fig.8c) and secondary curves in frontal plane and SOSORT angles in sagittal plane.

Using this system any subjective error is eliminated as it may occur in the case in traditional Cobb method. It also increases inter/intra subject reliability in first and following repeats.

2.2.4 3D registration of the spinal model with dorsal surface - „Patient-specific" 3D deformity model

Generic 3D model of the spine is adaptable and registerable to the dorsal surface. Using *ScoliosisSimulator-3DSpinalRegistration.catvba* macro, "patient-specific" model of deformity will be generated. Scaling factor will modify each vertebral model in 3 directions according to rigid registration principle (3D to 3D).

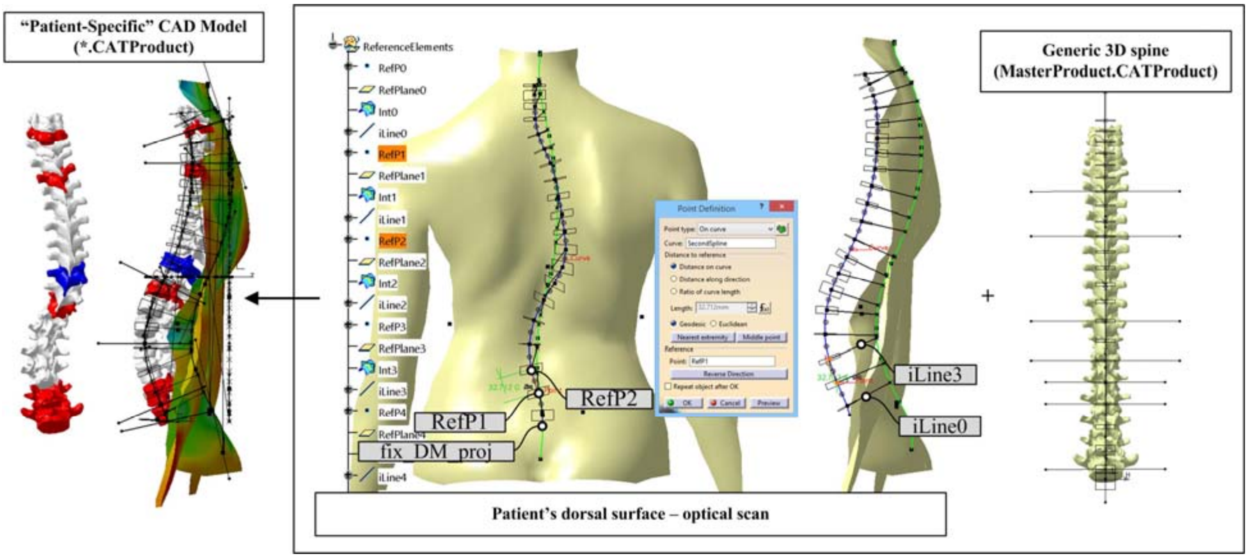


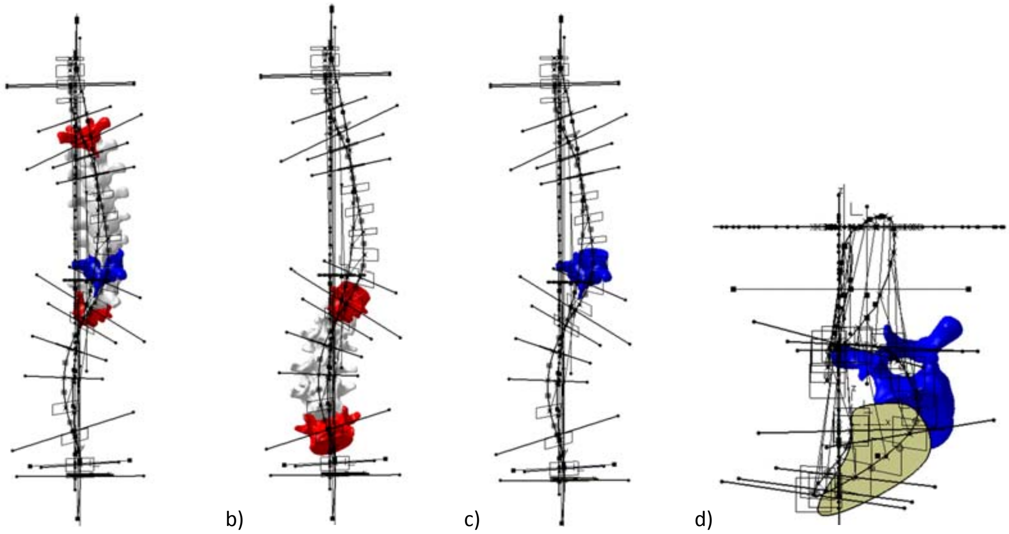
Figure 9: Registration and referencing of the generic 3D model of the spine to the dorsal surface - "patient-specific" model of the deformity

This model generates a set of internal and external parameters. As a particularly important are transpositions of vertebral body centroids and intervertebral discs. Transpositions have negative sign ("-") if the vertebral bodies are dislocated left from CVS line (Central Vertical Spinal Line), and positive ("+") if centroids are right from this line. The vertebra which is in a sense of absolute value the mostly dislocated is called apical vertebra. This vertebra belongs to the primary curve and is around of the peak of that curve [3].

2.2.4.1 Detection of end vertebrae, apex vertebrae and its transpositions

Each deviation of the spinal line from the straight line in frontal plane means transposition of some vertebral groups or its rotations. Vertebrae or intervertebral discs that have centroids near inflection points are end vertebrae/disc. Near those elements, curve has changing its curvatures. This research is focused on primary and secondary curves or segments of B-Spline line with Cobb angles greater than 10º.

Figure 10 illustrates primary curve (Fig.10a) in frontal plane between thoracic vertebrae **T11** and **T5** and its Cobb angle has value 57.786º (Cobb-XY2). Secondary angle has value of 49.708º (Cobb-XY3) with end vertebra **L4** (first vertebra of the curve) and end vertebra **T11** (last vertebra of the curve) (Fig.10b). End vertebrae of the deformity model are visualized with red color, and apex vertebra of the primary curve has the blue color.



a) b) c) d)

Figure 10: “Patient-specific” spinal model a) primary curve, b) secondary curve, c) apex vertebra T9, d) rotation of vertebra T9

In this case, the most rotated vertebrae (Fig.10d) has the most dislocated centroid of the vertebral body and it is thoracic vertebrae **T9** – apex vertebra (Fig.10c). Transposition parameter of this vertebra is *TranspT9FrmFixC7DM*.

3. RESULTS AND DISCUSSION

Besides demographic data about adolescents recorded in our database, developed macro generates about 110 diagnostic parameters. Length measures (mm) and angles (degrees), processed in the program Excel 2013 (Microsoft, USA) are statistically analyzed in the program SPSS v20 (Statistical Package for Social Sciences - SPSS Inc., Chicago, IL, USA), to determine the correlation coefficient (r) and linear relationship between the anatomical measures [18], [19], [20].

3.1 STATISTICS OF COBB ANGLES

We evaluated Cobb angles of the primary and secondary curves in female and male patients that are greater than 10º, and frequency of those curves. Since scoliosis is primarily diagnosed in frontal plane, our focus was frontal segments of the deformity curve and its relation with SOSORT-these recommended angles.

From 141 male patients, curve greater than 10º is identified in 118 cases (Tab.1). Minimal angle of the primary curve was 10.01º, maximal 53.3º, and mean 19.85±8.87º. Secondary curve had 76 males. Minimal angle of the secondary curve was 10.05º, maximal 38.89º, and mean 17.52±7.11º.

Table 1. Descriptive statistics of Cobb angles for females and males

DESCRIPTIVE STATISTICS OF COBB ANGLES FOR FEMALES AND MALES

	N		Minimum		Maximum		Average values		Standard deviations	
	F	M	F	M	F	M	F	M	F	M
Cobb angle of primary curve	215	118	10.40	10.01	62.73	53.30	25.5294	19.8531	12.13237	8.87963
Cobb angle of secondary curve	183	76	10.20	10.05	49.71	38.89	20.6265	17.5287	8.77586	7.11579
Valid N	231	141								

Table 2. Frequency of deformity segments in females and males

NUMBER OF DEFORMITY SEGMENTS IN FEMALES AND MALES

		Frequency		Percent		Valid percent		Cumulative %	
		F	M	F	M	F	M	F	M
Valid	Curves less than 10º	15	23	6.5	16.3	6.5	16.3	6.5	16.3
	Single curves	33	41	14.3	29.1	14.3	29.1	20.8	45.4
	Double curves	61	39	26.4	27.7	26.4	27.7	47.2	73.0
	Triple curves	79	22	34.2	15.6	34.2	15.6	81.4	88.7
	4-segment curves	38	10	16.5	7.1	16.5	7.1	97.8	95.7
	5-segment curves	5	5	2.2	3.5	2.2	3.5	100.0	99.3
	6-segment curves		1		.7		.7		100.0
	Sum	231	141	100.0	100.0	100.0	100.0		

From 231 female patients, curve greater than 10º is identified in 215 cases (Tab.1). Minimal angle of the primary curve was 10.40º, maximal 62.73º, and mean 25.52±12.13º. Secondary curve had 183 females. Minimal angle of the secondary curve was 10.20º, maximal 49.71º, and mean 20.62±8.77º.

Table 2 shows that single curve is most dominant in male patients (41%), than double curves (39%) and triple curves (22%). Same table shows that in female adolescents, the biggest prevalence has triple curve type (34.2%), than double (26.4%). Figure 11 illustrates 3D models of two patients (female, Fig.11a and male, Fig.11b) dexrtoconvex scoliosis with the greatest angles of primary curves recorded in 372 patients.

3.2 STATISTICS OF SOSORT-THESE ANGLES

According to recommendations of SOSORT consortium, macro generates angles in frontal plane between specific vertebral bodies (SosortFrontL1L5, SosortFrontT10L2, SosortFrontT2T5, SosortFrontT5T12) and in sagittal plane (SosortSagittalL1L5, SosortSagittalT4T12), [21].

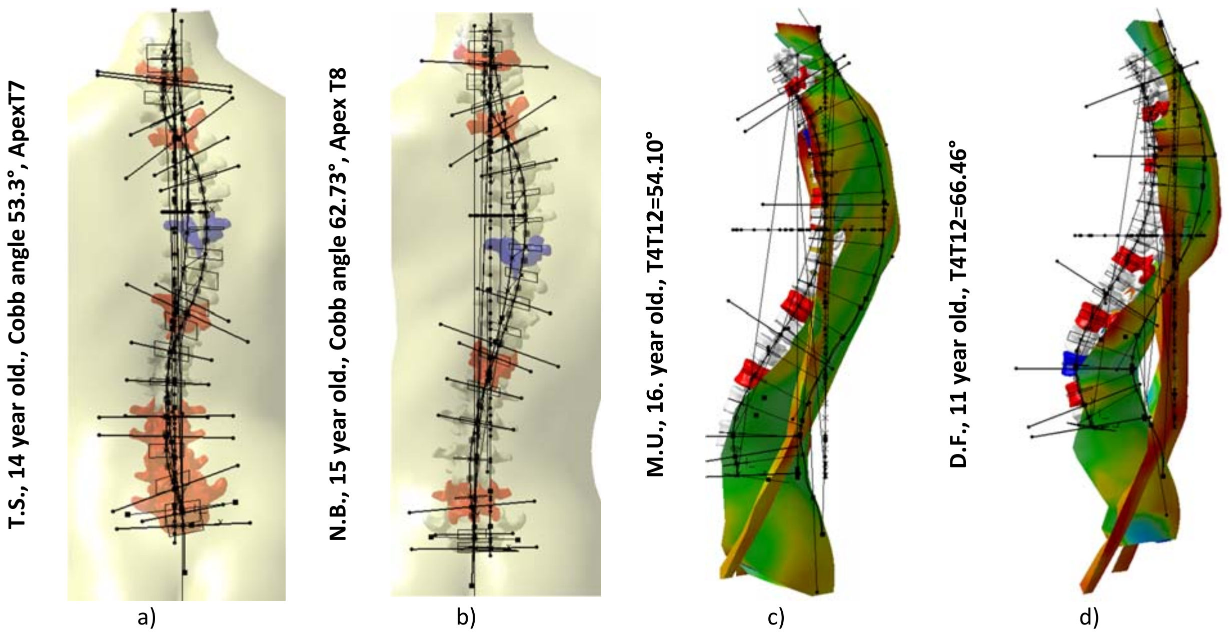


Figure 11: Maximal Cobb angles of primary curves in adolescents a) male, b) female; Maximal SOSORT angles in two cases c) SosortSagittalT4T12 - hyper kyphosis and d) SosortSagittalL1L5 - hyper lordosis

Figure 11 shows the maximum angles of kyphosis and lordosis that were defined based on SOSORT recommendations. Extreme values of these measures are *SosortSagittalT4T12* and *SosortSagittalL1L5* in 2 samples from 372 adolescent datasets (Fig.11c and Fig.11d).

3.3 STATISTICS OF APICAL VERTEBRAE, AXIAL ROTATIONS AND TRANSPOSITIONS

According to positions of the most dislocated vertebrae, the most dominant type of scoliosis in males is thoracic scoliosis (51.1%) as well as in females (63.2%), than thoracolumbar (33.3% and 23.8%) and lumbar (15.6% and 13%). Similar analysis is presented in [22].

The most frequently scoliosis type in female patients was right scoliosis (dextroconvex) in 119 cases (68.4%), followed by 27 left thoracic, 31 left thoracolumbar, 24 right and 31 left thoracolumbar, and 15 left and 15 right lumbar scoliosis.

The most frequently scoliosis type in male patients was left scoliosis (sinistroconvex) (50.4%). Evidence showed 38 right and 34 left thoracolumbar scoliosis, followed by 18 right and 29 left thoracolumbar, and 8 left and 14 right lumbar scoliosis. Statistics of vertebral transpositions showed that the most frequently dislocated apex vertebra in female patients is **L1** or **T9**, and in males is **L1** or **T12**.

Axial rotation of the vertebra **L5** according to [22] is 2.2±1.7º. Our study showed similar analysis of the L5 relative rotation (2.19±2.60º). We found that the biggest absolute rotation in our study is axial rotation with value of 36.63°of the thoracic vertebrae **T8** (parameter AxialRotT8).

3.4 CORRELATION BETWEEN INTERNAL AND EXTERNAL DEFORMITY INDICATORS

One of the greatest challenge in development of the modern diagnostic systems for quantification of scoliosis progress is estimating a correlation level between internal and external deformity indicators [23]. We calculated Pearson's correlation coefficient among many internal and external indicators [14], and here presents only few.

3.4.1 Correlation of SOSORT-these and Cobb angles in frontal plane

It is stated in literature that Cobb's angles in diagnostic procedures is "gold standard" for quantifying deformities on x-rays. One of the key issues is the estimate the degree of correlation of these angles with dorsal angular measures. Calculation of Pearson's correlation coefficients between frontal SOSORT's angles and primary Cobb's angles generated on the middle spinal line using VBA macro are shown in the following table (Tab.3).

Table 3. Correlation of frontal deformity angles

CORRELATION OF FRONTAL DEFORMITY ANGLES

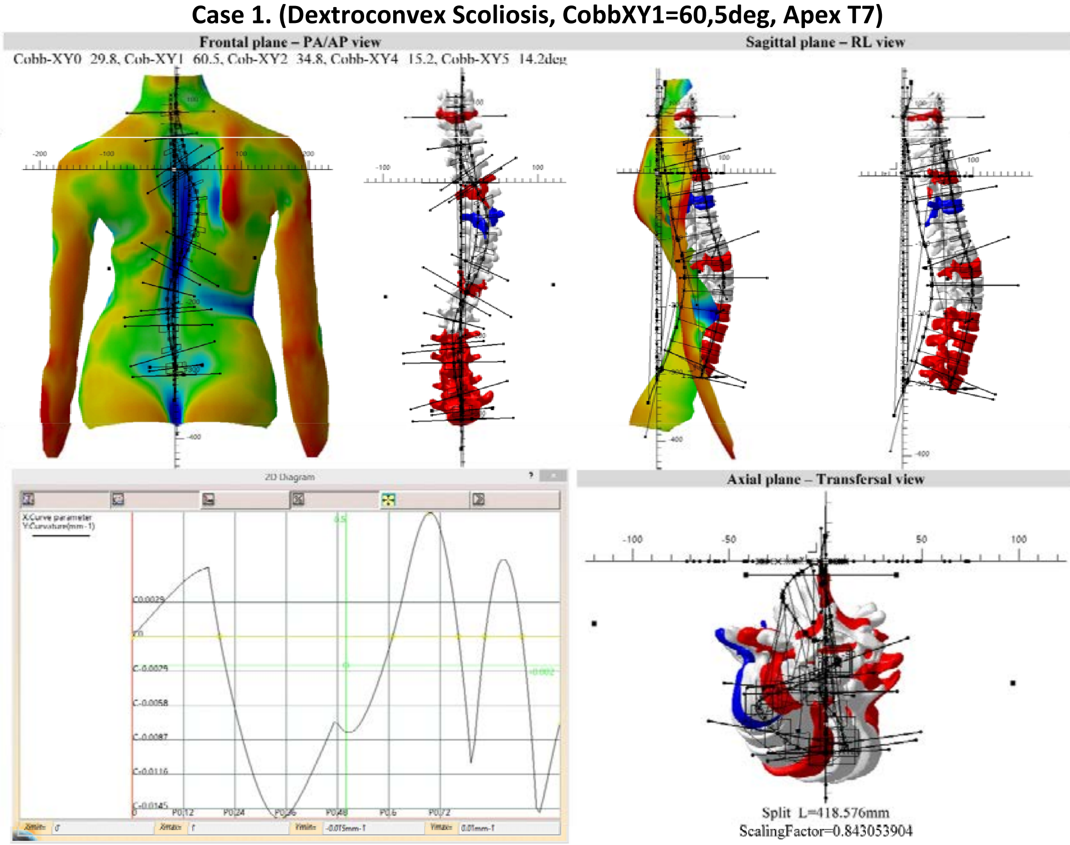
		Scaling Factor	PrimaryFrontal Cobb	SosortFront L1L5	SosortFront T10L2	SosortFront T2T5	SosortFront T5T12
ScalingFactor	Pearson Correlation	1	-.085	-.072	-.139**	-.023	-.136**
PrimaryFrontalCobb		**-.085**	1	.587**	.572**	.419**	.742**
SosortFrontL1L5		**-.072**	**.587****	1	.219**	.108*	.617**
SosortFrontT10L2		**-.139****	**.572****	**.219****	1	.245**	.302**
SosortFrontT2T5		**-.023**	**.419****	**.108***	**.245****	1	.260**
SosortFrontT5T12		**-.136****	**.742****	**.617****	**.302****	**.260****	1

**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).

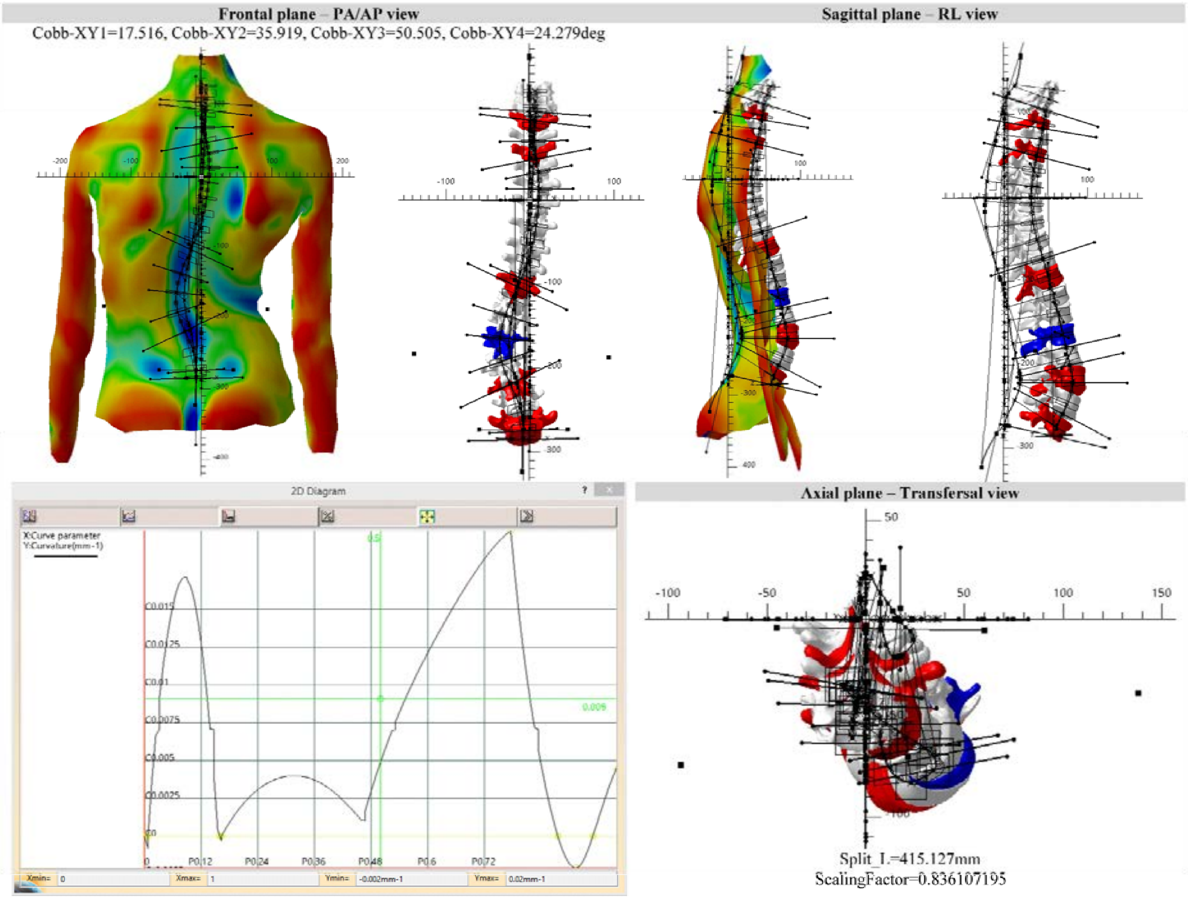
A particularly interesting is that among the high correlation parameters in the frontal plane is the correlation between *PrimaryFrontalCobb* and *SosortFrontT5T12* that reaches 0.742 ($r^2 = 0.55$ $\mathrm{r}^2 = 0.55$).

Besides many parameters that can be useful for clinicians, e-record of patient can contain visualization report. In that course we present two cases – patient deformity models:

Case 1. (Dextroconvex Scoliosis, CobbXY1=60,5deg, Apex T7)



Case 2. (Sinistroconvex Scoliosis, CobbXY3=50,5deg, Apex L1)



4. CONCLUSIONS AND FUTURE WORK

The main drawback of traditional diagnostic methods for the assessment of spinal deformity is their harmful effects, especially in cases of multiple exposures of patients to radiation. In addition to multiple exposures of patients to radiation, these methods require high image quality and correct positioning during recording, which is essential for the correct measurements of deformity angles, as well as highly qualified and experienced observers. In addition to these techniques, in clinical practice are used non-invasive techniques that are based on visual examination of patients and measuring the external parameters by reducing the need for harmful methods.

This paper presents a part of the results of the development of methodology for the diagnosis of spinal deformities. It is based on the application of methods of surface topography and reduced exposure to X-rays for patients suffering from idiopathic progressive scoliosis, aimed at elimination of radiation. The selected approach is based on the application of knowledgeware technology, as the integrator for patient-specific 3D modeling, visualization, simulation and monitoring of scoliosis. Spinal deformity modeling is based on generic 3D model of spine, generated from CT scans, which can be regenerated and adapted to the model of patient's dorsal surface. Developed system is tested on a representative number of adolescent (372), on models of their dorsal surfaces and results indicate that system is robust and can reduce need for radiographic examinations.

Although the incidence and prevalence of scoliosis is very high, there still is not a unique protocol for its clinical assessment and monitoring. The protocol we proposed takes into consideration the 3D nature of the deformity, with special accent on the sagittal plane and axial rotations, which is usually given insufficient attention in everyday clinical practice. Our system excludes subjective assessment and any writing/reading error, and it can be expected that this protocol will gain high value when measurements on subjects with scoliosis are performed. As the system is based on precise, quantitative and objective procedure for the analysis and visualization of human static posture on the basis of the detected anatomical landmarks can be given its potential applications and further development directions. A lack of reliable and generally accepted system for classifying adolescent idiopathic scoliosis causes usage of descriptive diagnosis of deformity or imprecise methods for quantifying and monitoring. Idiopathic scoliosis are of unknown origin, in which congenital aspect of deformity creation is excluded. Analyzing data obtained by diagnosis of representative adolescent patients, it is possible to develop a new classification scheme and identify the most common deformities in adolescents. 3D quantification and classification of spinal deformity remains a challenge because of the difficulty in translating complex geometric concepts and principles in a clinically acceptable method. Further efforts are focused on the identification of typical morphological characteristics of deformities that would enable grouping and comparing deformity lines and improve process of obtaining clinically useful and understandable representation of deformity.

Current version of the system is tested at Center for Physical Medicine and Rehabilitation, in Orthopedics and Traumatology Clinic at Clinical Center Kragujevac, Serbia and its implementation showed promising results, particularly in adolescent idiopathic deformities.

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