

The Quantification of Volumetric  
Asymmetry  
by  
Dynamic Surface Topography

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## Abstract

Approach

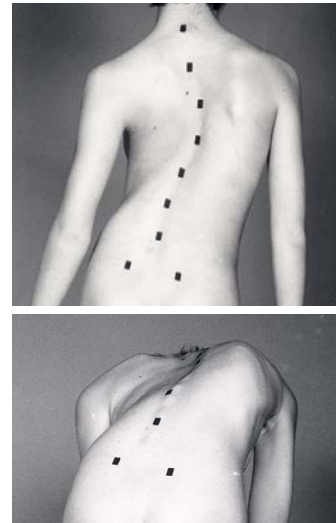
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Conclusion

The psychosocial impact of the cosmetic defect on Adolescent Idiopathic Scoliosis patients is an important factor that must be considered when developing treatment plans and monitoring outcomes. There is new emphasis on finding ways to quantify reliably paraspinous back surface volumetric asymmetry, with the objective of providing a scoring that can give an impression of the severity of the deformity at each clinical presentation.

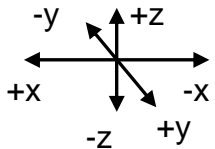
The aim of this study was to propose and test three numerical descriptions of volumetric asymmetry and to gain an insight into the effects of posture, breathing and sway on the reliability of the measures.



# Several measures to describe paraspinous volumes were investigated by calculating the:

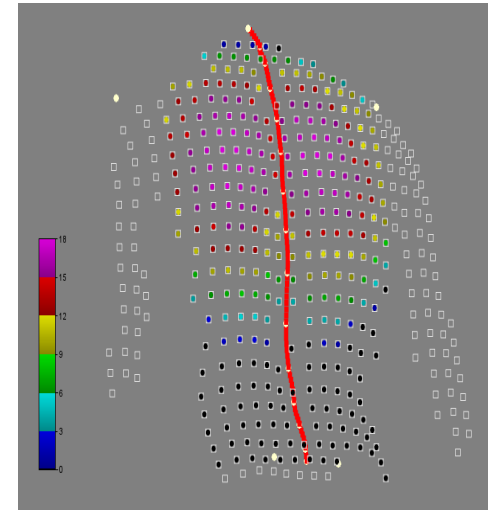
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- Means in the horizontal (x) and vertical (z) axes of groups of surface points located within seven equidistant coronal plane cross-sections either side of the line of the spine between a reference plane defined by the location of the vertebra prominens and posterior superior iliac spines and peak value in each acquisition sample.

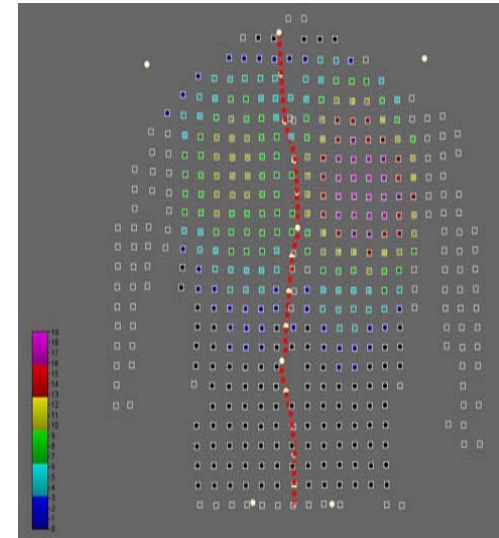


- The areas bounding groups of surface points located within twenty equidistant coronal plane cross-sections of the volumes each side of the line of the spine between the reference plane and peak value in each acquisition sample.

- The centres of mass of the areas of twenty equidistant coronal plane cross-sections of the volumes each side of the line of the spine between the reference plane and peak value in each acquisition sample.



Adult Subject

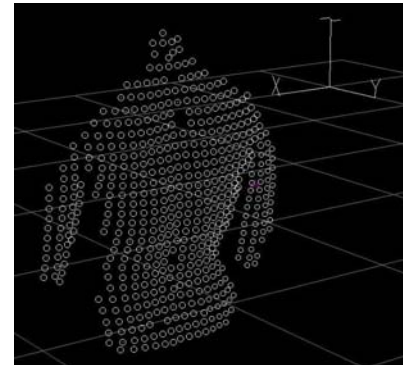


Simulated Scoliosis

**Equipment** The study used an obsolete and modified 6 Camera, VICON motion capture system (Vicon Motion Systems Ltd., Oxford, U.K.) to acquire surface data (3 cameras) and anatomical landmark positions simultaneously at a rate of 60 video frames/second. Point clouds projected onto subject backs were detected by the cameras from different views. Only bright circular images were acquired by each camera sensor, independent of the rate of subject movement and ignoring skin, fabric and other objects within the fields of view. Optical filtering prevented the spherical markers used for the identification of landmarks being detected by the surface cameras.



The three dimensional locations of the surface points in each frame were calculated using a photogrammetric reconstruction of multiple camera images. Reconstruction accuracy was found by the acquisition (n=1200) of a 910x980mm planar test object to be mean±SDmm;  $0.15 \pm 0.48$  in the vertical axis;  $0.13 \pm 0.33$  in the horizontal axis; surface noise  $0 \pm 2.0$ .



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**Methods**

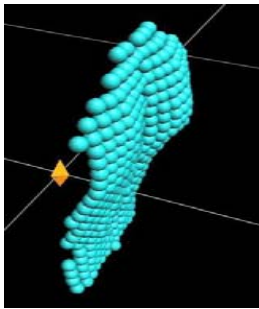
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**Participants** The study group consisted of 30 skeletally mature adults (26 male, 4 female) exhibiting no systemic disease, significant chronic musculo-skeletal disorder or condition and had not been previously diagnosed with Adolescent Idiopathic Scoliosis. The age range was between 25 and 63 years, with an average age of 34.93 years (SD 7.71 years). Male participant ages averaged 34.35 years (SD 5.87 years) and females, 38.75 years (SD 16.29 years). The majority of subjects were right handed (26 of 30) with two subjects exhibiting leg length inequality, determined by measuring the relative heights of the popliteal fold behind the knees, of 10mm left and 19mm right respectively. All participant heights were between the 5<sup>th</sup> and 95<sup>th</sup> age/gender percentiles to remove any impact of outlying anthropometries on the results.

**Protocol** Each subjects was asked to stand naturally, arms slightly abducted in front of the apparatus for 5, 1151 frame sequential (19.18 second) acquisitions resulting in 172,650 samples available for statistical analysis.

**Simulation** In order to gain an insight into the influence of a scoliosis on the proposed measures, a simulation programme introduced predictable asymmetry to the back shape and anatomical landmark data in one subject trial on the assumption that the underlying spine had progressed to a King Type II right 56<sup>o</sup> thoracic with a left lumbar 45<sup>o</sup> compensatory curve.

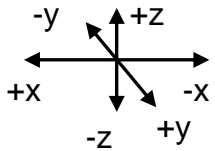


Scoliosis  
Simulation

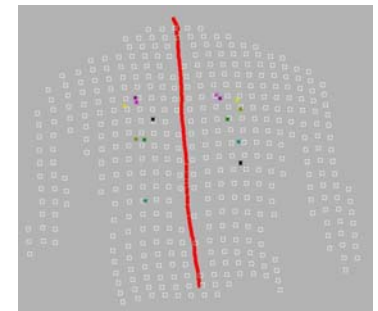
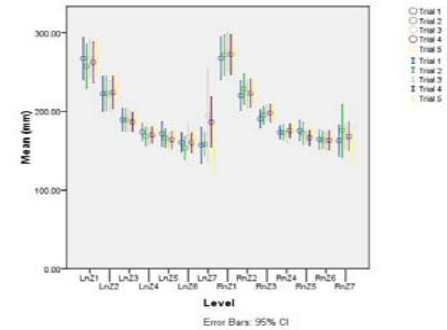
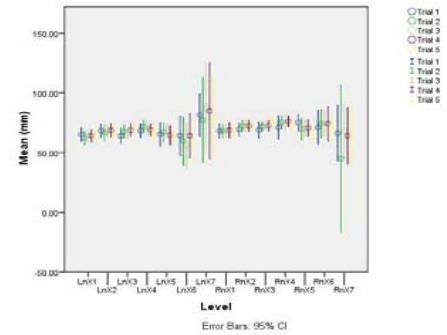
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## Coronal plane cross sectional mean positional patterns

The observed normalised mean values (related to the vertebra prominens) in the x-axis for 5 sequential trials, for all subjects were equidistant either side of the line spine between the lowest (Ln<sub>x1</sub> and Rn<sub>x1</sub>) and highest (Ln<sub>x7</sub> and Rn<sub>x7</sub>). The results in the z-axis demonstrated that there was a direct correlation between cross section levels and a reduction in differences between mean locations implying that the paraspinous thoracic volumes were similar in shape to a truncated cone. The observed variability particularly among the higher levels were due to a combination of postural, sway and breathing artefacts as well as differences in morphology among the study group. In both axes the results indicated that back shapes were symmetrical among the participants.



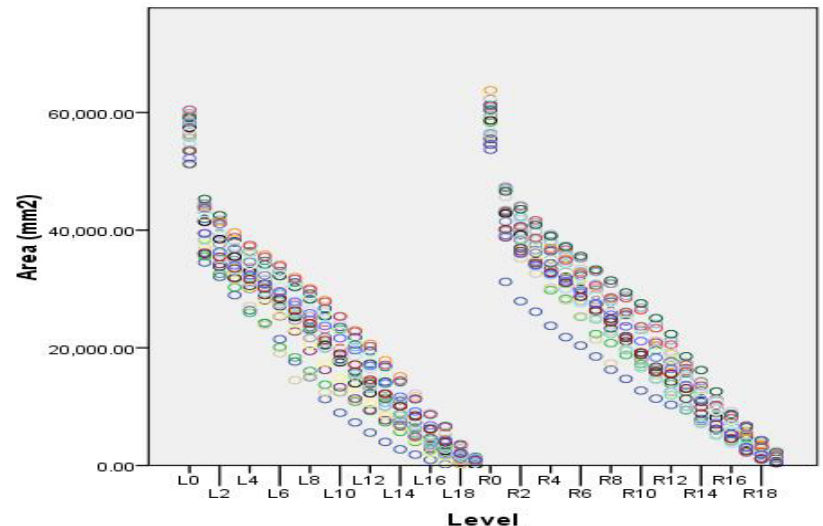
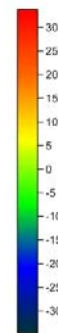
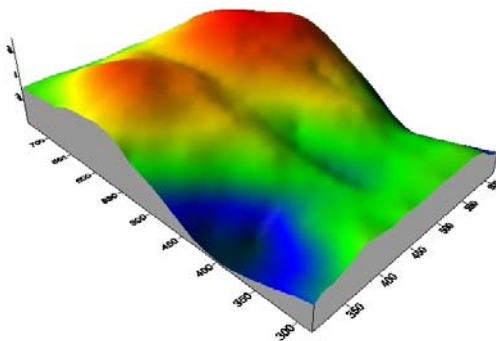
Paired sample *t-tests* were performed to establish if there was any significant differences between actual and simulated data and none was found.



Mean Positional Patterns

**Paraspinous Coronal Plane Cross Sectional Areas** The means of cross sectional areas either side of the line of the spine were compared between the lowest ( $L_0, R_0$ ) and peak ( $L_{19}, R_{19}$ ) for all subject trials. The results confirmed that the lowest levels were dominated by the whole back shape whereas the higher levels tracked the thoracic region volumes. The similarity in patterns confirmed the general symmetry of the group. Slope using left and right data was 1.0 mm mean , 95% confidence interval bounds were between 1.13 and 0.95) with a standard deviation due to individual asymmetries of  $\pm 0.55$ .

Paired sample *t-test* results indicated that the differences between the normal and simulated data areas were highly significant  $p < 0.001$  (left side  $t(19) = 5.33$  and the right  $t(19) = 7.15$ ). Differences in slope between the normal and simulated analyses were 0.99 and 1.42 respectively.



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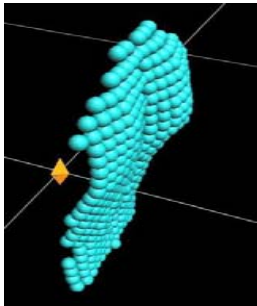
**Cosmetic Asymmetry Index** The normative results gave confidence that the Cosmetic Asymmetry Index (CAI) proposed here may have merit in quantifying back shape as it is dependent on the reliable quantification of volumes either side of the line of the spine. The CAI for the 150 adult acquisition trials were calculated and were found to have a mean value of  $74 \pm 52$  SD. The results indicate that there was significant variation in the averaged index values between subjects but it showed good specificity for individuals implying that the index may have potential as an indicator of changes in a patient as well as a general quantifier of cosmetic defect.

$$CAI = Const. \frac{\sum_{i=1}^{20} abs(\overline{LA}_i - \overline{RA}_i)}{(\overline{LA}_0 + \overline{RA}_0)}$$

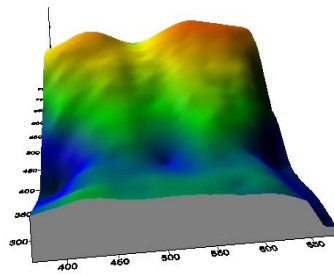
Where:

Const = 100  
 and  $\overline{LA}_i$   $\overline{RA}_i$  are the acquisition mean values of the areas at each coronal cross section

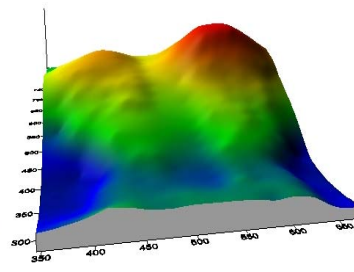
and  $\overline{LA}_0$   $\overline{RA}_0$  are the acquisition means of areas of all points.



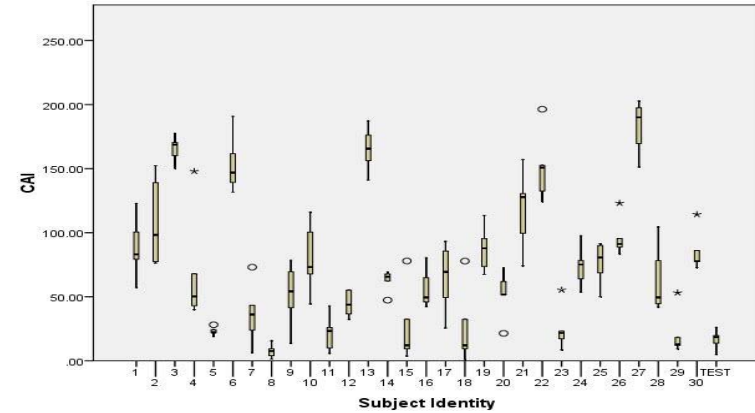
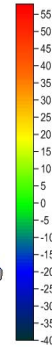
Simulated Scoliosis



BACK SURFACE SHAPE OF SUBJECT 25 WITHOUT SCOLIOSIS



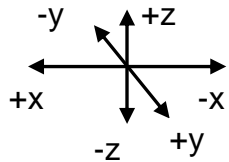
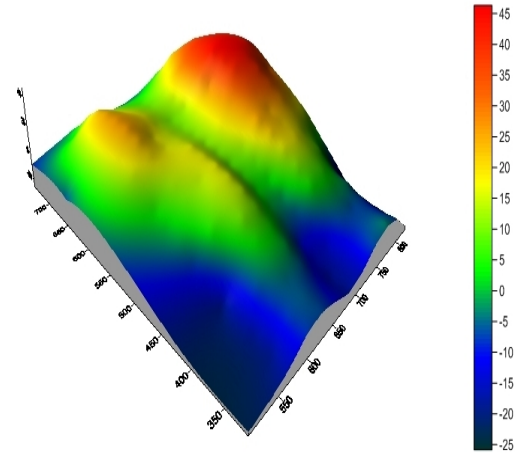
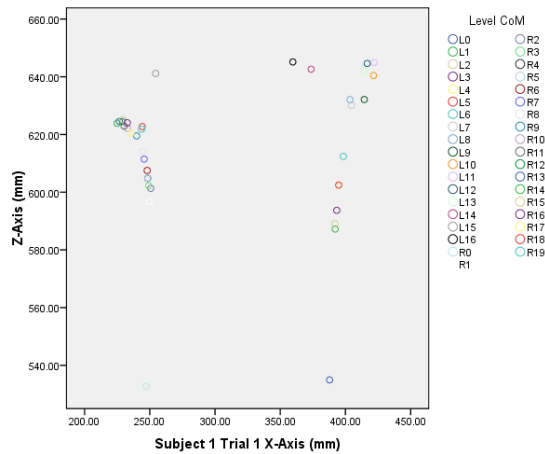
BACK SURFACE SHAPE OF SUBJECT 25 WITH A SIMULATED RIGHT THORACOLUMBAR & LEFT LUMBAR SCOLIOTIC CURVE



The Cosmetic Asymmetry Index increased from 76 calculated from the normal back shape (Subject 25) to 126 for the scoliotic simulation.

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**Centres of Mass** The means of the centres of mass of each coronal plane level either side of the line of the spine were calculated for the thirty adult subjects. In all cases the distribution of the centres of mass values correctly reflected the observed surface shapes by clustering where volumes peaked around the scapula and being more distributed if the volumes were more elliptical as for the right side of this example.



Paired sample t-tests were performed on the normative and simulated data to establish if there was any significant difference. The *t-test* results indicated that the differences between the normal and simulated areas were highly significant  $p < 0.001$  in the x-axis  $t(32) = -5.31$  and significant in the z axis  $p < 0.05$   $t(32) = -2.15$ .

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**Discussion** The algorithms to describe volumetric asymmetry by calculating the areas and centres of mass of 20 equidistant cross sections either side of the line of the spine were able to significantly identify a simulated cosmetic defect over a normal back shape. Comparing the relative locations and relational patterns of paraspinous cross section centres of mass values may also have application in assisting with the description of back shape asymmetry. To assess variability, the algorithms were normalised for all acquisitions and expressed as a % using:  $\text{Variability} = (\text{SD}/\text{Mean}) * 100$  to allow direct comparisons to be made between subject results. For paraspinous coronal plane cross section mean locations, the variability was observed as up to 6% and for areas and centres of mass measure up to 80% biased towards the higher cross sections. In the latter cases this was due to the effects of posture, breathing and sway on the increased number of cross sections calculated.

**Conclusions** Three new algorithms were proposed to describe volumetric asymmetry and applied to the measurement of the back shapes of 30 skeletally mature subjects not exhibiting any musculo-skeletal disorder with the goal of defining normative baselines. The measures of variability gave insight that the use of averaged rather than a reliance on single samples improved measurement reliability.

**Acknowledgement** The advice and guidance given by Professor P.H.S. Torr, Professor in Computer Vision and Machine Learning is gratefully acknowledged.