3D Body Scanning Applied for Human Torso Evaluation

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Abstract

Anthropometrically, humans are considered more-or-less bilaterally symmetric. However, several micro and macro factors perturb the symmetric nature of humans and other living organisms. Typically, human asymmetry may be quantified by measuring the individual components on either side of the body, i.e., right versus left arm length. This matched symmetry approach relies on specific landmarks. Though this is a valid method, the matching symmetry approach is not viable for the 3D torso because a torso's right and left sides cannot be separated precisely by a single plane when it comes to the human torso. Researchers have attempted to look for a single plane that volumetrically divides a human body based on the general assumption that the human body is bilaterally symmetric. In reality, the human body is a three-dimensional object that needs to be perfectly symmetric for such a plane to exist. However, the majority of human body shapes exhibit asymmetry of various degrees. Here, a novel non-invasive method is shown for estimating the rate of asymmetry in the 3d human torso using 3D body scanning technology and mathematical methods. The proposed method computes the asymmetry of a human torso by iteratively estimating localized symmetry in small 2D slices of torso scans and combining them to determine the global symmetry/asymmetry. 3D body scans of 30 subjects (15 males and 15 females) were used in this study to develop and evaluate the method. Here, the torso was defined as the upper part of the body from the cervical to the crotch-level, with hands removed at axilla point posterior left and right. The mathematical computations used the MATLAB programming tools. The developed method quantifies the degree of asymmetry on the human torso. The method is suitable for 2D and 3D surfaces and can compute asymmetry from 3D scans and other types of digital models. The technique has potential applications across various fields.

Keywords: 3d body scanning, asymmetry index, torso evaluation

1. Introduction

Symmetry refers to “the quality of something that has two sides or halves that are the same or very close in size, shape, and position: the quality of having symmetrical parts [1]. In biological entities, symmetry is a prevalent feature and an essential characteristic for movements and other survival mechanisms. Humans are considered more-or-less, bilaterally symmetric. However, several micro and macro factors perturb the symmetric nature of humans and other living organisms. Factors that could contribute to departure from symmetry include habitats with high population density, noise, nutritional stress [2], handedness, biomechanical pressure [3], high temperature [4], infections [5] and genetic issues [6]. The degree of symmetry, or asymmetry per se, varies from visually non-distinguishable (i.e., highly symmetric) to extremely noticeable (or highly asymmetric, as in the cases of Scoliosis). Quantifying the degree of symmetry is needed in several clinical and pathological analyses, as well as developmental and genetic theorizations. Characterizing the symmetric nature of the human body is typically performed by (a) comparing individual components on either side of a virtual plane, i.e., length of right vs. left arm, and (b) comparing the area or volume on either side of a plane, i.e., volume of the right vs left brain hemispheres. The former is called match symmetry, while the latter is object symmetry. Several techniques exist to characterize the degree of symmetry in both categories. However, they are limited in their applicability in measuring symmetry in three-dimensional (3D) torso objects. The match symmetry methods rely on specific landmarks and componentized measurements and are not well suited for measuring symmetry in a 3D volume. The object symmetry techniques exist for two-dimensional (2D) images and 3D volumes but are landmark-dependent. Most of the studies rely on anatomical landmarks to determine the mid-sagittal plane, and the process involved in estimating the mid-sagittal plane is often debated [7]. Furthermore, there is no existing method that can quantify the degree of symmetry on a digital 3D torso that is also independent of anatomical landmarks. This study shows a novel, non-invasive method for estimating the asymmetry rate in the 3D human torso using 3D body scanning technology and mathematical approaches. This method computes the asymmetry of a human torso by iteratively estimating localized symmetry in small 2D slices of torso scans and combining them to determine the global symmetry/asymmetry.

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2. Literature Review

2.1. Asymmetry estimation in 1D and 2D

A study on tennis player population showed that the dominant hand had a thick humerus for both men and women [8], indicating asymmetry. Later, [9] examined the body's asymmetry among white adults. They took measurements such as triceps skinfold, bi-epicondylar breadth, upper arm circumference, subscapular skinfold, calf circumference, and bicondylar breadth-femur on both the right and left sides of 94 males and 22 females. Significant levels of asymmetry were observed for bi-epicondylar breadth, upper arm circumference, and triceps skinfold. Leg measurements and subscapular skinfold showed no significant differences. Manning [10] explored the relationship between symmetry and running speeds among middle-distance runners for a total of 50 male subjects. Measurements like 2nd, 3rd, 4th, 5th digit, wrists, nostrils, and ears were recorded. Significant between-individual differences were noted for all the traits. However, they found that symmetric runners were faster than their asymmetric counterparts. Facial symmetry has been considered an important attractive factor and criterion for mate selection. More importantly, facial symmetry and symmetry restoration are crucial to maxillofacial surgery. Typically, facial symmetry analysis uses the identification of landmarks on the face and the linear/angular measurements measured bilaterally. Rikowski [11] studied body and facial asymmetry as attractiveness factors and their relation with body odor. Seven bilateral traits – handbreadth, elbow width, ear breadth, ear length, ankle width, wrist breadth, and foot breadth- were used as measurement variables to determine symmetry. Fluctuating asymmetry was found for measurements of ear breadth, ear length, and foot breadth. However, the study concluded that there was no significant relationship between body asymmetry and facial attractiveness. Another research on tennis players by [12] showed that nine bilateral traits measured on the humerus had higher asymmetry than the control group. Body part asymmetry was studied in patients with partial seizures. Out of the 282 patients analyzed, 88 showed body asymmetry. The study examined toe sizes, thumb sizes, popliteal crease levels, cubital crease levels, forehead sizes, temporal and maxillofacial bones, and gastrocnemii sizes. Body asymmetry in this study ranged from hemiatrophy of limbs (difference in the leg length) to atrophy involving the thumb or big toe [13].

The bilateral symmetry of Australian soccer and basketball players was measured by [14]. Bilateral traits were recorded and analyzed for matched symmetry from 52 subjects (26 basketball players and 26 soccer players). Measurements taken were categorized under skinfolds, girths, lengths, and breadths. The triceps, subscapular, biceps, iliac crest, supraspinal, abdominal, front thigh, medial calf, and mid axilla were grouped in skinfolds. Girth measurements were arm (relaxed and flexed), forearm, wrist, thigh, mid-thigh, calf, and ankle. Acromiale-radiale, Radiale-stylion, Midstylion-dactylic, Iliospinale height, Trochanterion height, Trochanterion-tibiale, lateral, Tibiale, lateral to the floor, Tibiale mediate-Spherion tibiale, Foot length, Humerus, and Femur were the length and breadth measurements. Significant directional asymmetry was found for triceps skinfold, arm-relaxed, arm-flexed, forearm, trochanteric height, and humerus. However, the two sports groups showed no significant differences in asymmetry. Investigations on symmetry play an essential role in planning operations and evaluating different surgical procedures like cleft lip and palate [15]. An anthropometric study with Kenyan distance runners by [16] measured six elite athletes' leg length, calf circumference, and ankle circumference and found no matched bilateral difference. Additionally, they tested the strength characteristics of both legs using isometric torque and isokinetic torque ratio and found no significant difference between the legs on the strength variable. The methods reported in all these studies relied on the bilateral traits or paired landmarks. None of the methodologies discussed are landmark-independent and applicable to torso asymmetry.

2.2. Asymmetry estimation in 3D

The need for volumetric bilateral symmetry estimation motivated studies towards 3D approaches. For example, breast asymmetry and its relationship to body size and fertility were studied among 500 British women. Mammograms were used to compute breast volume and breast height. The results showed bilateral asymmetry. Furthermore, breast volume, height, and weight were positively associated with breast fluctuating asymmetry, and women with large breasts had the slightest asymmetry [17]. Subsequent studies utilized 3D methods to determine breast asymmetry in women with idiopathic scoliosis [18] using 3D surface scans and girls with significant adolescent idiopathic scoliosis using magnetic resonance imaging [19]. The former study computed anthropometric measurements from 3D images. Five anthropomorphic measurements, i.e., suprasternal notch-to-nipple distance, inframammary crease length, nipple-to-inframammary crease, the horizontal comparative position of the left and right inframammary fold, and the hemithoracic circumference at the level of the most inferior point of the inframammary crease were measured on both sides and differences were calculated. Eder

[20] developed an alternative method to quantify breast asymmetry objectively. The authors used 3D surface images and evaluated the mean 3D contour differences between the right and the left side by superimposing the mirror image of the left breast over the right breast.

A new approach to measuring facial asymmetry using 3D computerized tomography (CT) images was developed by [21]. Patients with facial deformities were compared with normal subjects. Landmarks such as sella, dent, orbitale, porion, anterior nasal spine, U1I, U1M, L1I, L1M, menton, condyle, gonion, and superior point of coronoid were located manually on the CT images. Subsequently, semi-transparent 3D images showing facial surfaces, hard tissue, and landmark points were generated using imaging software. The Asymmetry index for bilateral and solitary landmarks was computed for normal subjects and patients. A chart was created comparing normal and facially asymmetric subjects. This new approach provided a more detailed evaluation of facial asymmetry than the traditional cephalogram method.

In general, it was reported that the 3D methods were superior regarding the observed differences and the error caused by inter-observer variations. The provided survey of the literature indicates that all of the methods found in the literature are (i) landmark-dependent and/or (ii) need human intervention at various steps of the processing. The match symmetry method requires componentized measurements such as arm length, etc. The object symmetry approaches typically use indirect steps such as transforming the object representation into other spaces. Those techniques that are direct also rely on manual landmarks. Furthermore, the existing techniques were not developed to address the need to characterize symmetry in a 3D human torso on the whole. Hence, there is a need for a method that can estimate symmetry for a non-uniform 3D volume, is robust to natural posture, computationally less complex, and less dependent on anatomical landmarks and human intervention.

3. Methods

3.1. Data collection

3D body scans of 30 subjects (15 males and 15 females) were used in this study to develop and evaluate the proposed method. The subjects were selected from an existing 3D scan database. Five subjects from three weight groups (5 x 3 = 15 subjects) were randomly selected per gender (see Figure 1). The selected 3D scans (with a native format of *.ply*) from the database were imported into the Polyworks® CAD utility. Here, the torso was defined as the upper part of the body from the cervical to the crotch level, with hands removed at the Axilla point posterior left and right (Figure 2). The mathematical computations used MATLAB programming tools.

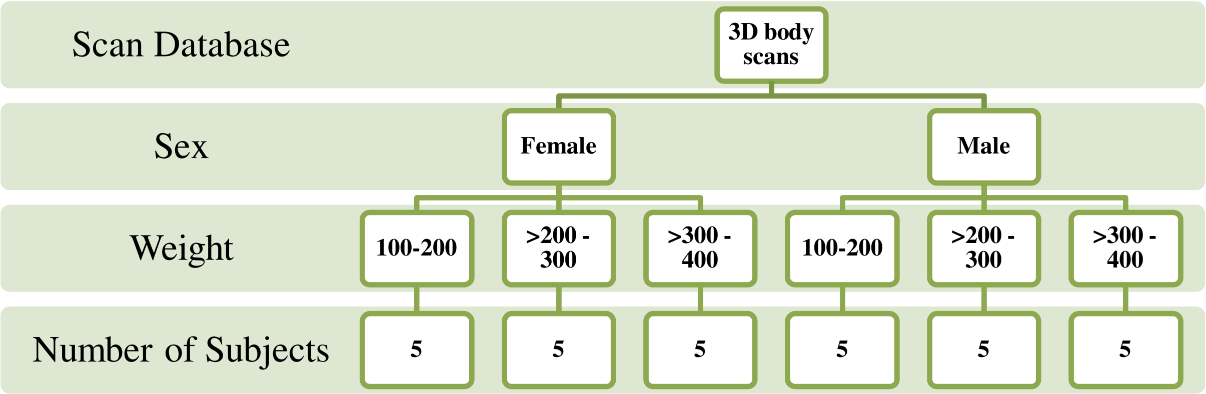

Fig.1. Selection of 3D body scans from the database

3.2. Computing the Asymmetry Index

After extracting the 3D torso, the next step involves developing a method to determine the line of symmetry for the entire torso. The technique used in this research was to subdivide the 3D torso into several thin 2D slices (Figure 2b), and individual planes of bifurcation (termed as the local line of symmetry) were determined for each slice. Subsequently, the bifurcation lines were linked along with the slices in the z-direction (vertical axis) to determine a global surface that divides the 3D volume into two equal halves (the global surface of symmetry). Within each slice, the line of symmetry was computed using an iterative process where a sliding line gradually moves at the rate of 2 mm from right to left direction and computing the area of the right and left halves of the cross-section at each increment.

As the sliding line moves from right to left on the cross-section, it divides the area into two closed curves. The area of one of the closed curves was compared against the total area of the cross-section to determine if that closed surface represents half of the total area.

3.3. Computing the Area of Closed Surface

To determine the area under the closed surface, which is the cross-section here, Green's theorem was used (see Equation 1). This theorem allows determining the area of a closed contour using its line integral, i.e., integrating the contour along the perimeter to determine its area (Riley, Hobson, & Bence, 2006).

$$\oint_{\partial D} \boldsymbol{P(x,y)dx + Q(x,y)dy} = \iint_{D} \left(\frac{\partial Q}{dx} - \frac{\partial P}{dy}\right)\boldsymbol{dxdy} \qquad (1)$$

The location at which the area of the closed surface becomes equal to half of the total area was considered the local line of symmetry for that cross-section. This local midline divides the section into two halves for each cross-section based on their areas (Figure 2c). However, there is a possibility that the equal areas of cross-sections may have different shapes, i.e., the contour of the two halves need not be identical, thereby causing asymmetry. To determine the shape differences, one half of the cross-section was mirrored on the other half to estimate and the non-overlapping areas were estimated. In Figure 2c (top), A represents the right hand side, and B represents the left half. The region of interest (ROI) was the partial area of cross-sections that did not overlap after mirroring (Figure 2c, bottom).

After computing the ROI for the individual 2D slices, the global Asymmetry Index (AI) was defined as the proportion of the total ROI to the cumulative half-area of the slices, given as,

$$\text{Asymmetry Index (\%)} = \frac{\sum_{i=1}^{n} Area\ of ROI_i}{\sum_{i=1}^{n}(Area\ of\ slice_i * 0.5)} \times 100 \qquad (2)$$

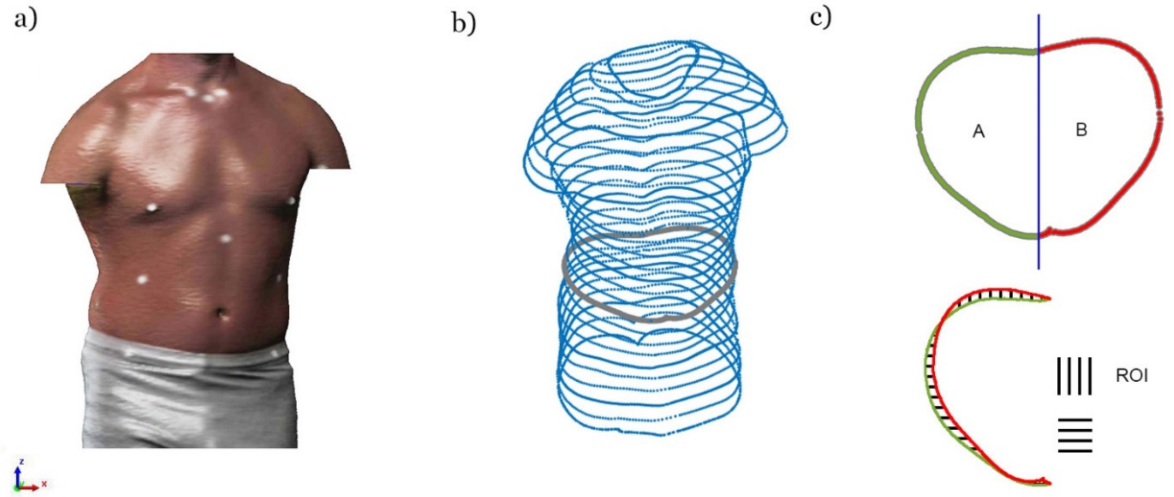

Fig. 2. a) 3D scan of human torso b) cross-sections of the torso in x-y plane c) Local symmetry line and the region of interest

4. Results and Discussion

In order to validate the developed measure whether it can rate a symmetric object to be “symmetric” and an asymmetric object as “asymmetric with a certain degree”, the following approach were taken. A 3D cylinder model comprised of 10 slices was chosen to perform this validation (see Figure-3). The dimensions are arbitrary units. The global line of symmetry is a single plane passing through the centroid of the object. An estimated asymmetry of ‘0.0e-12’ shows that the object is perfectly symmetric, as expected.

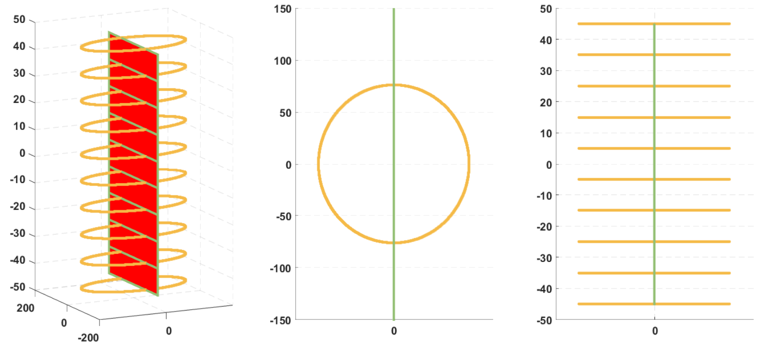

Fig.3. The global plane of asymmetry on the known geometry is a single plane that runs through the centroid of the object.

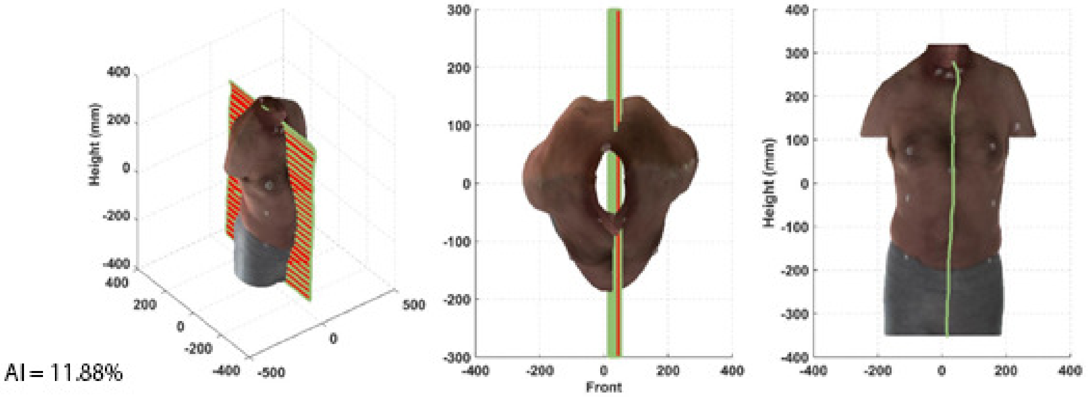

Fig.4.The computed plane and AI for a sample male subject.

Figure 4 shows a sample final output from the applied method. The person shown in the figure has an AI of 11.88 percent. The left panel shows the global plane on a perspective view and the middle panel shows the top view and the right one shows the front view. As evident, the plane of symmetry is not a straight plane rather a planar surface.

Asymmetry has been agreed, consensually, as a phenomenon prevailing in the human torso. However, its estimate remains subjective mainly due to a need for more reliable objective methods. This research developed and validated a novel method to estimate the degree of asymmetry in a human torso. This method used digital representations of human torsos obtained from a repository of 3D scans. It is a surface topography-based technique that detects the local plane of symmetry in 2D cross sections and links them across the entire volume to estimate the global plane of symmetry in 3D space. The line of symmetry was estimated independent of anatomical landmark references. The area of the cross-section was the parameter on which the local line of symmetry was estimated. Alternatively, the local plane of symmetry could be computed using Euclidean distance from the extremum as a parameter. Nevertheless, that would be a 1D parameter and is relatively sensitive to contour deviations in cross sections compared to a 2D measure, such as the area. Another approach to compute the global plane of symmetry would be to use the principal axes as a guiding plane that divides the torso. This method may be quite trivial and computationally less expensive. However, it would lack the spatial resolution needed for several medical applications such as scoliosis recovery, i.e., it may not be able to provide a localized degree of symmetry and how it propagates across the torso. Another approach could be to use the principal axes on the 2D cross sections as the local plane of symmetry. However, it is prone to errors due to physiological variations and requires human intervention to ascertain the proper orientation.

In the present study, the plane of symmetry was computed in the sagittal plane. The technique, however, is general and can be applied to other planes including transverse and coronal directions. Furthermore, the method is less constrained in terms of the definition of what comprises a torso. The technique of computing the cross sectional area was based on the Green’s theorem. It uses a line integral to compute the area of a closed surface. This is advantageous in cases where the 3D representation is a surface contour rather than a filled volume, such as in the present case where the scanner captures 3D surface topography alone. If the cross section happens to be a mesh rather than a contour, other methods of triangulations can be employed to compute the area, but at the expense of computational intensity. The present method is particularly advantageous in terms of its simplicity and robustness, and is based on strong mathematical techniques. Furthermore, the technique is not dependent on the type of image capturing system. If a 3D object cloud can be represented in terms of its Cartesian positions, the technique would allow us to compute its asymmetry.

5. Conclusion

A new method has been developed and demonstrated to evaluate symmetry in human torso. The developed method has potential to be applied in various fields for multiple purposes. The method is suitable for both 2D and 3D surfaces and can compute asymmetry as long as a closed contour can be formed. For research domains, the methods can serve as an evaluation tool and also as a means to test hypotheses pertaining to asymmetry. Clinical evaluation can quantify the torso deformation of scoliosis patients using this technique and can develop braces for the patients. The technique can also be helpful for the 3D clothing software in measuring the asymmetry of 3D models and adjusting the garment patterns accordingly.

References

[1] Merriam-Webster, “Definition of SYMMETRY,” Merriam-webster.com, 2015. https://www.merriam-webster.com/dictionary/symmetry

[2] P. B. Gray and F. Marlowe, “Fluctuating asymmetry of a foraging population: the Hadza of Tanzania,” Annals of Human Biology, vol. 29, no. 5, pp. 495–501, 2002, doi: https://doi.org/10.1080/03014460110112060.

[3] C. Ruff, B. Holt, and E. Trinkaus, "Who’s afraid of the big bad Wolff?: 'Wolff’s law' and bone functional adaptation," American Journal of Physical Anthropology, vol. 129, no. 4, pp. 484–498, 2006. http://doi.org/10.1002/ajpa.20371

[4] V. M. Zakharov, "Future prospects for population phenogenetics," Chur, Switzerland: Harwood Academic Pub., 1989.

[5] A. P. Møller, "Parasitism and Developmental Instability of Hosts: A Review," Oikos, vol. 77, no. 2, pp. 189–196, 1996. [Online]. Available: http://doi.org/10.2307/3546057.

[6] G. Townsend, "A correlative analysis of dental crown dimensions in individuals with Down syndrome," Human Biology, vol. 59, no. 3, pp. 537–548, 1987.

[7] R. T. Willing, G. Roumeliotis, T. R. Jenkyn, and A. Yazdani, "Development and evaluation of a semi-automatic technique for determining the bilateral symmetry plane of the facial skeleton," Medical Engineering & Physics, vol. 35, no. 12, pp. 1843–1849, 2013. http://doi.org/10.1016/j.medengphy.2013.06.006

[8] H. H. Jones et al., "Humeral hypertrophy in response to exercise," The Journal of Bone and Joint Surgery. American Volume, vol. 59, no. 2, pp. 204–208, 1977.

[9] L. M. Schell et al., "Directional asymmetry of body dimensions among white adolescents," American Journal of Physical Anthropology, vol. 67, no. 4, pp. 317–322, 1985. http://doi.org/10.1002/ajpa.1330670404

[10] J. T. Manning and L. J. Pickup, "Symmetry and performance in middle distance runners," International Journal of Sports Medicine, vol. 19, no. 3, pp. 205–209, 1998. http://doi.org/10.1055/s-2007-971905

[11] A. Rikowski and K. Grammer, "Human body odour, symmetry and attractiveness," Proceedings. Biological Sciences / The Royal Society, vol. 266, no. 1422, pp. 869–874, 1999. http://doi.org/10.1098/rspb.1999.0717

[12] H. Haapasalo et al., "Exercise-induced bone gain is due to enlargement in bone size without a change in volumetric bone density: a peripheral quantitative computed tomography study of the upper arms of male tennis players," Bone, vol. 27, no. 3, pp. 351–357, 2000.

[13] G. C. Y. Fong et al., "Body part asymmetry in partial seizure," Seizure, vol. 12, no. 8, pp. 606–612, 2003. http://doi.org/10.1016/S1059-1311(03)00138-9

[14] G. R. Tomkinson, N. Popović, and M. Martin, "Bilateral symmetry and the competitive standard attained in elite and sub-elite sport," Journal of Sports Sciences, vol. 21, no. 3, pp. 201–211, 2003. http://doi.org/10.1080/0264041031000071029a

[15] M. Bashour, "History and current concepts in the analysis of facial attractiveness," Plastic and Reconstructive Surgery, vol. 118, no. 3, pp. 741–756, 2006. http://doi.org/10.1097/01.prs.0000233051.61512.65

[16] P. W. Kong and H. De Heer, "Anthropometric, gait and strength characteristics of kenyan distance runners," Journal of Sports Science & Medicine, vol. 7, no. 4, pp. 499–504.

[17] J. T. Manning et al., "Breast asymmetry and phenotypic quality in women," Evolution and Human Behavior, vol. 18, no. 4, pp. 223–236, 1997. http://doi.org/10.1016/S0162-3095(97)00002-0

[18] C. Denoel et al., "Idiopathic scoliosis and breast asymmetry," Journal of Plastic, Reconstructive & Aesthetic Surgery: JPRAS, vol. 62, no. 10, pp. 1303–1308, 2009. http://doi.org/10.1016/j.bjps.2008.04.031

[19] J. Ramsay et al., "Is Breast Asymmetry Present in Girls with Adolescent Idiopathic Scoliosis?" Spine Deformity, vol. 2, no. 5, pp. 374–379, 2014. http://doi.org/10.1016/j.jspd.2014.05.002

[20] M. Eder et al., "Objective breast symmetry evaluation using 3-D surface imaging," The Breast, vol. 21, no. 2, pp. 152–158, 2012. http://doi.org/10.1016/j.breast.2011.07.016

[21] M. Maeda et al., "3D-CT evaluation of facial asymmetry in patients with maxillofacial deformities," Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology, and Endodontics, vol. 102, no. 3, pp. 382–390, 2006. http://doi.org/10.1016/j.tripleo.2005.10.057