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Assessment of Body Volume Asymmetry in Healthy Adults via 3D Scanning: Impact on Chest Wall Mobility

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ABSTRACT

A symmetrical body with evenly-developed sides may look better, but in order for humans to adapt to his environment, perfect symmetry of right and left sides hardly exists. This study aimed at determining the right and left body volume asymmetry and its impact on chest wall movements during breathing cycle via 3-D scanning. A sample of 121 adults (78 males and 43 females), age 18 – 44 y was recruited for the research. All the participants were scanned using Artec 3-D scanner to determine total, right and left body volumes; and with Hamamatsu 3-D scanner to determine chest wall mobility during breathing cycle after four reflective stickers had been fixed on the participants; two to delineate the end-points of bideltoid breadth, one on the sternum at the level of the third rib and another at the corresponding level in the posterior median furrow, to delineate anterior-posterior diameter. Comparing the right and left body volume, the right volume was significantly greater than the left body volume in both males and females (P<0.05). Relative to end tidal position, the anterior chest made highest vertical movement, followed by the left deltoid, then the right deltoid, with the least at the dorsal surface in inspiration. Durng expiration, the anterior chest, right deltoid and left deltoid displayed a similar downward movement, but the least magnitude was obtained at the back. 3DS has provided an insight that body side volumes can affect upward and downward distances displaced by thoracic wall at different phases of breathing cycle.

INTRODUCTION

Bilateral asymmetry of paired components of the body had been in evolution of humans over the years and have helped humans to adapt to his environment (Tomkinson and Olds,2000), as perfect symmetry of two body parts or paid organs hardly exists (Lima-de-Faria,1997; Rhodes et al., 2001). It refers to variations in characteristics between the two sides of the body which can be influenced by genetic, environmental factors and the differential use of body segments (Burdukiewicz et al.,2020; Stagi et al.,2023).

Valen (1962) outlined the classifications for which deviations from symmetry for a given characteristic can be. Directional asymmetry is characterized as a trait that is mostly developed on one side of the body in a population (Klingenberg 2015). Fluctuating asymmetry (FA) are those characteristics naturally, that are expected to develop symmetrically but they deviate (Valen, 1962; Watson and Thornhill, 1994). FAs are seen as evidence of environmental stress and health evolution of an individual or organism (Longman et al., 2011; Manning et al., 1997). FA is not easily detected because the bilateral variation is usually very small and entrenches challenges in its measurements

Various methodologies for evaluating body symmetry exist, however, anthropometry is usually recommended because of its reproducibility in assessing bilateral and segmental differences in compared body parts (Jones 2023). Until the recent time, analysis mostly employ a limited number of landmarks to represent the structure of interest in normal 2D photographs.al., 2018). A study on tennis player population indicated asymmetry as the dominant upper limb had thicker humerus for both men and women (Jones et al., 1977). Bilateral symmetry was conducted on Australian soccer and basketball players (26 soccer players and 26 basketball players). Measurement taken included skinfold thickness, girths, lengths, and breadths. Significant differences were observed for triceps skinfold thickness, arm-relaxed, arm-flexed and forearm girths; and trochanteric height and humeral height (Tomkinson et al., 2003).

Body volume symmetry estimation has been found to be accurately measured using 3-D scanning approaches. For instance, research involving British women investigated the links between breast asymmetry, body size, and fertility, looking into how these elements correlate with one another. The result showed bilateral asymmetry (Leinster, 1997). 3-D imaging technology for quantifying segment shape and volume has been developed in a way that the technology is easy to use and has recently become affordable. Studies have been conducted to establish the effectiveness of certain 3 D imaging techniques in accurately measuring the volume of the body or specific body segments (Daneen and Haar, 2013; Ng et al., 2016).

This study was designed to investigate bilateral body volume asymmetry in healthy adults via 3-D scanning and determine its impact on chest wall mobility.

MATERIALS AND METHODS

Recruitment of participants

A sample of 121 adults (78 males and 43 females), age 18 – 44 y was recruited for the research based on advertisement via a body composition flier and via e-mails seeking healthy adults for a single session body composition measurements. The participants were drawn from various ethnicities (Caucasians, Black Africans, Asians and Indians) but the greatest proportion came from a black African student community resident in Aberdeen and was mostly Nigerians. Easy communication and understanding between operator and participants enhanced the recruitment of a larger number of Nigerians living in Aberdeen. Each participant was given at least 24 hours to read through the participant information sheet and affirm the desire to take part or to withdraw. All participants were instructed to avoid meals for at least 3 hours before the measurements were taken. To ensure that the participants were fully hydrated, they were made to drink at least 60 cL water 20 minutes before the commencement of the measurements.

All measurements took place in purpose-designed research laboratories N516e and N516f of the Sir Ian Wood Building, RGU, Garthdee campus. In addition to the information sheet given to each participant in advance, a brief explanation of the measurements and the opportunity to ask questions related to the study was given to all participants on their arrival. All that was involved in the research study was explained to the participants, and all those who wished to continue gave their consent to participate by signing the consent form.

Inclusion criteria

Only apparently healthy adults within the age range of 18 – 60 y were allowed to participate in the research. However, the accessible age range was 18 – 44 y, which it was decided to implement, as there was an abundance of available individuals within this range. Such individuals are more likely to be healthy than older individuals (who might otherwise have skewed the data).

Exclusion criteria

Owing to hormonal changes during pregnancy and the consequence on altered tissue masses, distribution and densities, pregnant women were excluded. The pregnant women were identified based on oral reporting of those affected.

Ethical approval: All these research investigations were undertaken according to the provisions of the Declaration of Helsinki in 1995 (as revised in Edinburgh, 2000) and approved by the Robert Gordon University Ethic Committee.

Precaution for epilepsy

As a precaution for using structured light with portable scanner, each participant was screened for epilepsy (photo-sensitive epilepsy which is known to affect approximately 1 in 2000 people). This was done by administering a screening form to all participants investigating individuals who had suffered from epilepsy or had anyone in the family lineage who suffered from epilepsy.

Procedures for body scanning using the portable Artec 3D Scanner

In the scanner position, end tidal posture, each participant abducted his/her legs from the midline while looking forwards. The time for a full body scan acquisition was up to 45 seconds. As a result, the participant's arms were stabilised with a pair of orthopaedic working poles which eliminated any movement artefact. In order to reduce the breathing artefact which could result to blurring anatomical surface as it moved, the participants were also asked to maintain minimise breathing. With practice, scan acquisition time reduced to about 30 s.

The Artec L Portable 3D scanner produces and projects a structured light onto the body surface. The irregular body surface distorts the structured light, and the cameras record the distorted structured light on the body contour. The dedicated software merges adjacent scan fragments into the viewed image in real-time as the scan progresses.

The scans were processed through the techniques of global registration (aligning scan fragments with one another), fusion (accurately merging fragments into a single surface), hole filling and smoothing. Analysis and subsequent measurement extraction was performed using Artec Studio 9 software.

Through the use of digital landmark placement on the crotch, jugular notch and posterior median furrow the body was divided into L and R through the introduction of a sagittal plane using Artec Studio 9 software as illustrated on fig 1.

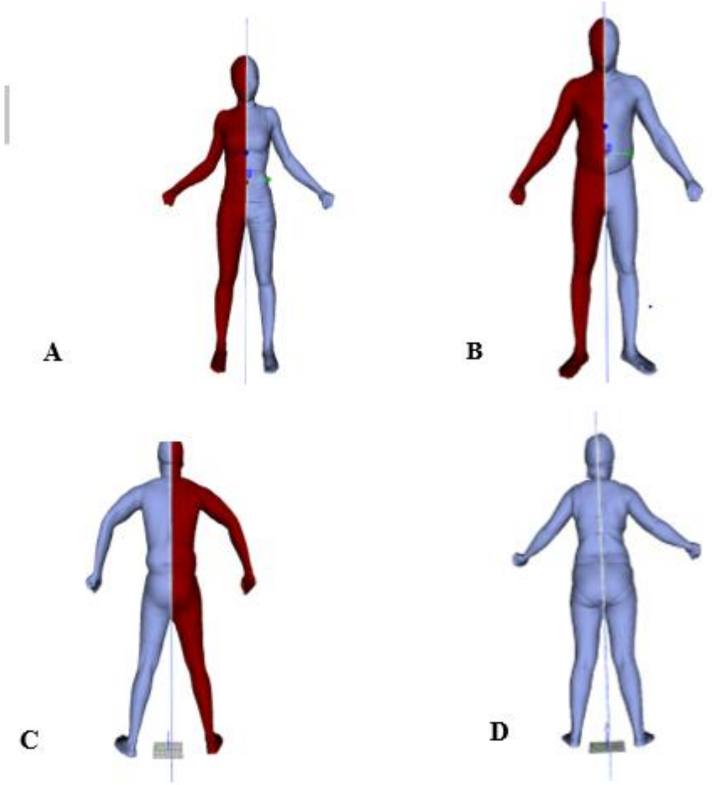

Fig 1. Division of the body into left and right-side volumes using Artec studio 9software. A, and B show the plane passing through the crotch and jugular notch of female and male respectively. C and D show the plane passing through the crotch and posterior median furrow of male and female respectively.

Procedures for body scanning using the Hamamatsu Photonic 3D Scanner

The 3D scans were acquired using a Hamamatsu BLS 9036 fixed scanner (Hamamatsu Photonics, UK). Using physical-digital landmarks, each participant was pre-landmarked with four reflective stickers. A set was affixed, each on the most lateral aspects of the L and R deltoid to delineate the end-points of bideltoid breadth (BDB). Another set was affixed, one on the sternum at the level of the third rib and at the corresponding level in the posterior median furrow, to delineate chest depth (anterior-posterior diameter). These landmarks resolve into xyz data points in the subsequent software analysis so these dimensions can be extracted. Different scans were acquired by participants adopting different postures, and being at different points in the breathing cycle. In the 'egress' position the participant stood upright with legs adducted to the midline and the arms extended and medially rotated to fix the palms on the lateral aspect of the thigh. For the 'scanner' position, the feet were shoulder width apart and legs and arms were abducted from the midline and with the hands extended, the palms were oriented in an anterio-posterior axis. Following the instructions from the operator, three different scans were extracted in egress position: end tidal, inspired and expired; while a posture: end tidal was scanned for scanner position. The time for each measurement lasted for approximately 10 seconds (acquisition mode was set to high resolution).

The scanner output involves a horizontal laser line array projected onto the body surface from four synchronized scan heads and merging the points acquired by different cameras as a point cloud. For the system's software (Body Line Manager version 1.3) to segment the body appropriately, five primary landmarks were identified at the vertex, C7 (nape), L and R axillae and crotch. All scans were processed and subsequently analysed using its proprietary software to produce a digital solid image that data can be extracted from (Fig. 2).

Fig. 2. Hamamatsu 3D model in 'scanner' position end tidal for measurement extraction

Statistical analysis

Before statistical analysis, the normality of the data was tested via a Kolmogorov-Smirnov test. Technical error of measurement (TEM) was used to evaluate measurement reproducibility. Paired T-tests were used to compare changes in thoracic depth during inspiration and expiration, bilateral difference in volume between the left and right side of the body through midline. Significance was taken at $P<0.05$. Statistical analysis was performed using SPSS version 21(SPSS Inc. Chicago, IL).

RESULTS

The physical characteristics of the participants which included age, stature, weight and body mass index were presented on table 1.

Table 1. Physical characteristics of participants

	Males (n =78)		Females(n =43)	
	Mean	**SD**	**Mean**	**SD**
Age (year)	27.8	7.5	23.6	4.2
Stature (cm)	177.5	6.8	165.5	6.7
Weight (cm)	77.9	13.0	60.4	9.4
BMI (kg/m^2)	24.8	3.6	22.1	3.0

Body volume asymmetry

The volume of right and left sides was investigated in a sample of 75 males and 44 females. Measurements were acquired of body volume and through the location of surface landmarks using portable Artec 3DS software, a sagittal plane passing through the groin, jugular notch, mid-distance between the two eyes and through the posterior median furrow was used to divide the body into right and left volume. Comparing the right and left body volume, the right volume was significantly greater than the left body volume in both male and female as shown in (Fig. 3).

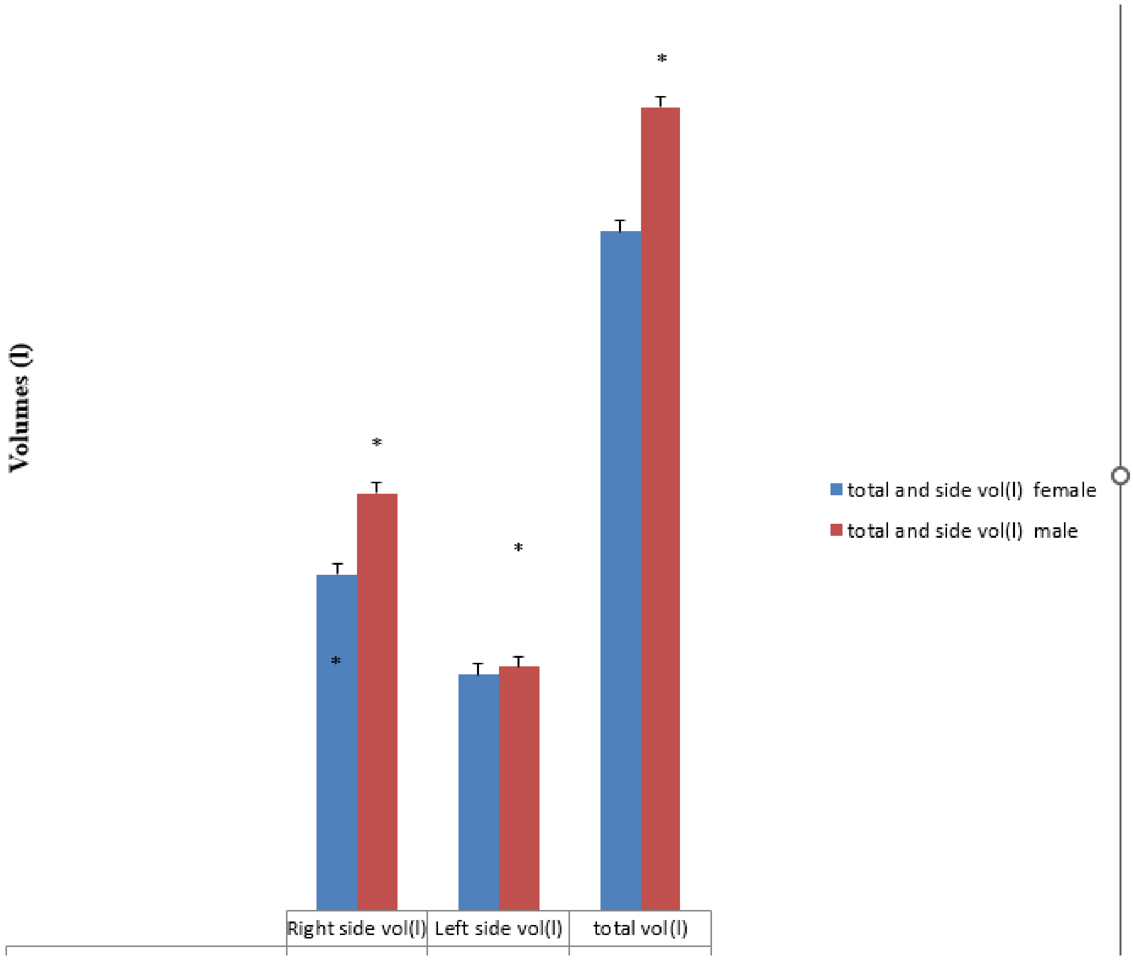

Fig. 3. Bar chart of total body volume, right and left body volume showing error bars. Blue bars represent female and red bars represent male. L-R comparison * P<0.0001, n=35.

Asymmetric impact on chest wall mobility

75 males and 44 femles were also measured with the Hamamatsu 3DS, and chest wall mobility was investigated by placing reflective landmarks on the mid-sternal distance (chest), on the corresponding level to mid-sternal distance at posterior midian furrow (back) and at the most lateral aspect of deltoid on both sides (right and left deltoid). Mean values were depicted in Fig. 4. A, showing chest wall mobilty during inspiration. Relative to end tidal position, the anterior chest made highest vertical movement in the sample, followed by the left deltoid, then the right deltoid. The least vertical movement occurred at the dorsal surface (i.e. at the back, at a corresponding level to the chest) and males displayed downward movements at the back during inspiration. In recoiling of the thoracic cage on expiration, (Fig. 4. B) the anterior chest, right deltoid and left deltoid displayed a similar downward movement, but the least magnitude was obtained at the back, and in females there was an upward movement at the back during expiration.

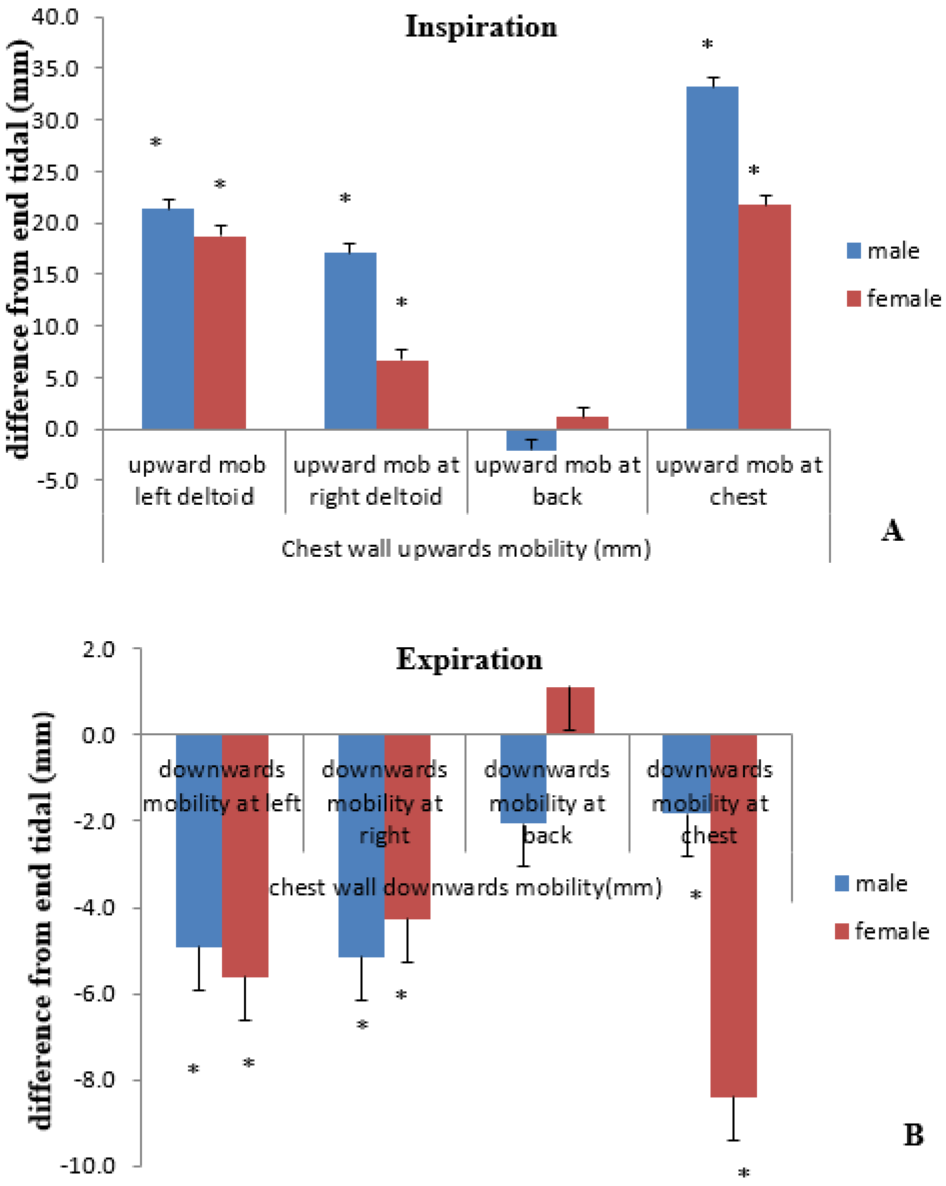

Fig. 4. Movement of key landmarks on the chest wall relative to end tidal during inspiration and expiration in males and females. A indicates inspiration, and generally upward mobility while B indicates expiration and generally downward mobility. Blue bars represent landmarks movement in male while red bars represent same in females, * = P<0.05, n=75 males and 44 females.

DISCUSSION

By combining portable 3DS and Hamamatsu 3DS it was found that the left and right sides' volumes of the body were significantly different, and their upward and downward mobility with the breathing cycle varied. The mean right-side volume was larger than the left side volume. However, most of the participants are right-handed and the preferred hand side may be expected to be more active than the other, with the consequence that additional connective tissue services this additional load. This makes sense if individuals are larger on the side of their preferred hand. Further assessment on its possible impact on the upwards and downwards movement of the chest wall indicated that although the anterior chest wall, which was delineated with a reflective sticker on the level of the 3rd costal cartilage on the sternum had the highest upward mobility, the left side compared with the right covered greater distance, while the least movement was recorded at the back. This could be explained by the fact that the lung is normally larger on the right (with three lobes) than the left (with two lobes).

In simple volumetric terms, a symmetrical body with evenly-developed muscle groups may look better, and as it has no apparent weak points, one side can be taken as a reflection of the other. In this circumstance, any measurement taken on one side can be applied to the other side (Stewart *et al*., 2011; Muller *et al*., 2016). The body has different tissues which have different physical properties obeying different physical laws. Balanced tissues and forces would theoretically minimise the risk of trauma, whereas highly asymmetrical forces (or only slightly asymmetric forces, repeated on multiple occasions) might overload body structures and lead to injury, for example of the foot (Azevedo *et al*., 2017). However, the theory of body symmetry can only be taken so far. The internal body is highly asymmetrical. The muscular and skeletal systems both observe a principle of specificity (Jones *et al*., 1989) whereby unilateral loading will cause tissue strengthening / increased mass and/or density. For instance, fencing is a unique in asymmetrical movement hence it imposes high physiological demand in neuromuscular co-ordination, strength and power with profound effect on the musculoskeletal system (Murgu, 2006). On the other hand, quantification of symmetry is important in the evaluation of body image and body dissatisfaction (Lin and Kulik, 2002; Richardson and Paxton, 2010). Individuals with less symmetry may have poorer body image than those who are highly symmetrical. Although this is a relatively unexplored area in 3D scanning terms, such a study would be quite difficult to pursue in practice– because the acquisition of any 3D scan is based on the assumption that the body can adopt a 'neutral' posture. Before studies to explore the relatively small differences in symmetry anticipated are undertaken, it would be important to establish how variable postures can appear for any single individual.

Body asymmetry is seen in the relative differences in muscle strength, motion, flexibility, balance, and mechanics between sides of the body, and is one factor often highlighted as a risk factor for injury. In terms of gait during movements, body asymmetry resulting from bilateral inequality of volumes and thus mass may require asymmetry of movement, although the extent to which this may happen will depend on the degree of difference between the two sides. While it may be relatively common for asymmetry to exist in humans, for instance small variances in leg length and size, scoliosis or ankle flexibility, some of these may be beyond the ability of anthropometry to detect, even for experienced measurers or high-precision 3D scanning equipment (Shambaugh *et al*., 1991; Trivers *et al*, 1999). A compensation of the body's asymmetry may happen quite automatically without conscious thought – as can be readily seen when modifying the walking gait to carry an object in one hand. It appears though each side of the body is a replica of each other but with 3DS the volume variations can be quantified.

CONCLUSION

Although posture has been reported to affect chest-wall motion (Vellody *et al*., 1978; Verschakelen and Demedts, 1995; Nozoe *et al*., 2014) 3DS has provided an insight that body side volumes can affect upward and downward distances displaced by thoracic wall at different phases of breathing cycle. This could theoretically be linked to size inequality between left and right lungs.

A further study limitation of scanning the body at the extremes of ventilation is that some participants tend to bend forward during expiration and others tend to hyperextend the trunk during inspiration. Some others find it difficult to comply fully with the instructions of the operator. A further investigation should be carried out on athletes who are used to exerting maximal effort and may be able to comply with the instructions of operator to validate it. In order to further elucidate these small differences, a larger sample will be necessary – so this would necessarily involve a large expensive study, which might be difficult to justify. Most potential for this might be within the realm of asymmetrical sports and injury risk, or body dissatisfaction, although such a study might also require to establish the reproducibility of standing posture in addition.

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