Literature Review

Bilateral Symmetry of Different Anatomical Regions

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Introduction

Symmetry is prevalent within the human body and is studied for clinical reasons such as reconstructive surgery. Different regions of the body show great bilateral symmetry but require different methods of measuring this symmetry. This literature review focuses on methods of obtaining craniofacial, pelvic and torso symmetry. This research is useful to future studies of symmetry within these anatomical regions.

Methods

The articles used within this review were found through numerous search engines such as Google Scholar, PubMed, Scopus and U of A Library databases. The keywords searched were "anatomical symmetry", "craniofacial symmetry", "pelvic symmetry", "torso symmetry", "landmark based" and "reflection". To organize the articles all information was placed in a spreadsheet, and folders for all the PDFs were created. Mendeley reference management was used to order and cite all papers found.

Discussion

Symmetry within the human body is a sign of good health and expresses the ideal bony geometry. Bilateral symmetry is easily found in different anatomical regions of the body, and there are different approaches to calculating the symmetry of these regions, which can be used in clinical research as well as in the preparation of reconstructive or plastic surgery. Three-dimensional (3D) methods are still undergoing research; however, their use is extremely important in the determination of symmetry of the human body due to its 3D nature. Baclig et al. studied 3D symmetry through reflection, rotoinversion (a combination of reflection and rotation) and translation (a process of reflection and rigid movement) [1]. These methods are non-invasive, markerless and do not require the skills or interpretation from a trained operator, making them useful in the evaluation of symmetry. This method can find the plane of symmetry and requires minimal time, expertise or training [1].

CRANIOFACIAL

Landmark Based

One of the areas of research heavily focused on in this literature review is the craniofacial region. To determine facial symmetry/asymmetry, a few different methods can be used, however, the most common method is landmark based. Researchers will take 3D images and find landmarks that can be used to determine the symmetry of the head and face [2]– [5]. Martini et al. aimed to propose a new way of determining the best possible approach to calculating forehead symmetry for children with craniosynostosis, which is a birth defect in which the bones in a baby's skull join too early [2]. Using 3D computed topography (CT) scans and reference points, optimal symmetry was determined from a single center point and deviation was quantified through an algebraic method. This method introduced a landmark-based 3D analysis tool for the calculation of the degree of asymmetry of the forehead level [2]. In a different study with 533 healthy children (325 male patients and 203 female patients) with a range of ages from 0 to 18, Cho et al. used full head stereophotogrammetrical images of each subject and compared them to a perfectly symmetrical model [3]. Up to 60 different landmarks were used to evaluate the symmetry of each subject's data. The Euclidean distance (straight line) from the center of the head and every point on the deformed template was calculated, which allowed for the calculation of the asymmetry of each subject [3]. In this study by Yanez-Vico et al. 21 subjects' (11 female and 10 male) CT scans were collected, and this data was then converted into three-dimensional images [4]. Landmarks were then determined around the skull, and from this multiple reference planes were created to evaluate skeletal asymmetry. This was done by calculating the distance between different points and finding the difference. The greater the difference, the more asymmetric the skull is [4]. The midsagittal (MS) reference plane is directly involved in the quantification of asymmetry, and this can be found on three-dimensional computed tomography (CT) scans of the head. For this study conducted by Kim et al., five normal dry human skulls were used, as well as twenty normal adults (8 female and 12 male) [5]. CT scans were taken of all subjects and the data was then converted to three-dimensional images of the craniofacial structures to calculate the MS plane. Twenty reference points of the skull base region and 11 points of the facial region were set for three-dimensional CT scans. From these reference points, 51 possible candidate planes were evaluated [5]. Through the use of landmarks on 3D images, researchers can determine the symmetry of the face, and this information can be used in the planning of plastic or reconstructive surgery.

Principal Component Analysis (PCA) and Iterative Closest Point (ICP)

Another method that has been more recently discovered and used is Principal Component Analysis (PCA) and Iterative Closest Point (ICP), which is the alignment of two shapes by finding the closest distance between clouds of points. Researchers use this method as it is more automatic and efficient in determining the symmetry of an object, as well as eliminates room for error [6]–[8]. Determination of craniofacial symmetry is important for reconstructive plastic surgery, and typically symmetry is calculated by manually identifying cephalometric landmarks from computerized tomography (CT) scans. However, midline planes for symmetry determined by manual cephalometric landmarks can result in less accurate estimations of symmetry and are very time consuming. Roumeliotis et al. developed a new method that combines principal component analysis (PCA) and iterative closest point (ICP) alignment methods to surface models of craniofacial CT scans [6]. This method was applied to 32 adult males ages 20 to 40. A symmetry plane was determined and using a custom program that reflected the model across the symmetry plane, the symmetry was calculated from the offset of the original and reflected model [6]. In this phantom study done by Pinheiro et al., a skull model from the GrabCAD database was used, which then had different geometrical transformations applied to it so it could simulate different types of facial growth and asymmetries [7]. They developed a new protocol to follow that can be used to determine craniofacial symmetry, and it consisted of using PCA on the model, followed by ICP and then PCA again. For 3D skull alignment, the protocol proposed is fully automated and allows for an accurate and landmark free estimation of the true symmetry plane of the human skull [7]. Di Angelo et al. conducted a study using 20 skulls, segmented from anonymous CT scans, two healthy real skulls and 18 real defective skulls with large defects [8]. The mirroring and weighted registration method (MaWR) was proposed for bilateral symmetry estimations of human faces. It is based on an iterative registration algorithm which minimizes an objective function properly designed to filter out any kind of asymmetries [8]. All of these methods rely less on trained operators and more on computer-aided software, which allows for faster evaluation, reduced error and reduced need for highly trained people.

Comparing Methods

A few studies attempted two kinds of methods to determine facial symmetry and compared them to see which one was more accurate [9], [10]. Launonen et al. studied children with deformational plagiocephaly (DP) (also known as flat head syndrome) as DP is believed to be a risk factor for facial asymmetry in infants ages one to three years [9]. Included in this study were 75 children (35 female and 40 male) with the age range one to three years, and only 23 patients had a history of DP in infancy. Subjects underwent three-dimensional stereophotogrammetric imaging of the head, and these scans were converted into 3D models. For the surface-based method of quantifying facial asymmetry, the 3D image was taken and mirrored across the sagittal plane. Then, the average distance (mm) between the original and mirrored images was calculated, which then allowed for the calculation of the symmetry of the face. For the landmark-based facial symmetry parameters, angles were calculated from different landmarks in 3D space. The difference between different angles calculated showed how symmetrical the face is (the lower the value the more symmetrical). Researchers found that facial symmetry tended to improve from one to three years of age in a normal birth cohort, and that previous DP does not seem to transfer to facial asymmetry [9].

This study done by Damstra et al. aimed to determine if there were any clinical differences between 3D cephalometric midsagittal planes used to describe craniofacial asymmetry and a true symmetry plane derived from a morphometric method based on visible facial features [10]. To conduct this study, 14 dry skulls (9 symmetric and 5 asymmetric) were used in both processes. For the first process, the skulls were scanned using cone-beam computed tomography (CBCT) images, and then the landmarks were digitized. After that, the software automatically constructed the cephalometric 3D midsagittal planes. For the second process, the morphometric method, the original and mirrored surface models were matched using partial Ordinary Procrustes Analysis (OPA) (when one shape is compared to another). First the object was mirrored, then the shape was aligned through translation and rotation, and finally the midsagittal plane was determined. In the end, it was found that there is a difference between 3D cephalometric midsagittal planes and the true plane of symmetry determined through morphometric methods, the difference being that the 3D constructed planes may be less accurate compared to the true symmetry plane [10]. This means that it may be more worthwhile to take the morphometric approach when determining the asymmetry of the craniofacial region, especially in surgery.

PELVIS

Myofascial Treatment

A myofascial release is the application of a low load, long duration stretch into the myofascial complex with the goal of treatment being the restoration of the optimal length of this complex, decreasing pain and improving function [11]. To reduce low back pain, asymmetries of the pelvis need to be corrected, and a myofascial release treatment can be very effective in correcting symmetry. First, 10 patients (male and female) had their posture and range of motion evaluated by a Metrecom. The tester would collect data on different reference points of the pelvis and find the distance between these points. The subjects were then separated into a control group and an experimental group by means of flipping a coin, and the experimental group was the only one to receive the myofascial treatment. After the experimental group received the myofascial treatment, the previous procedure was repeated. The distance from the anterior superior iliac spine (ASIS) (a reference point on the pelvis) and a central reference point was collected pre- and post-evaluation for each group, which allowed the researchers to determine the impact of the myofascial treatment. They found that the myofascial treatment allowed the pelvis position to change from asymmetric to more symmetric. This treatment is effective in allowing change of the pelvic position to become more symmetrical [11].

Closest Point Algorithm

The pelvis tends to show great bilateral symmetry, and closest point algorithms can be used to determine this symmetry which aids in the virtual reconstruction of the pelvis [12]–[14]. This study done by Kumar et al. used ten different computed tomography (CT) scans to analyze the symmetry of the pelvis [12]. Using Mimics software, the scans were converted into 3D models, and from there the volume and percentage difference of each side of the pelvis was calculated. Then one of the sides was reflected and aligned with the other side using a closest point algorithm. These sides were compared, and a deviation colour map was formulated to show the difference between the two sides. The pelvis seemed to show a good degree of symmetry from this research [12]. The symmetry of the pelvis was investigated by Ead et al. with computer-aided design (CAD) software, which in the future will allow the non-fractured side of the pelvis to be used in the development of patient-specific models for fracture reconstruction [13]. 14 CT scans of intact pelvis were collected for this study (11 males and 3 females), and these scans were converted into 3D models using Materialize-Mimics. Then the right side of the pelvis was mirrored on the left and deviation analysis took place. It is found that the pelvis has a high degree of symmetry, which can be extremely helpful in the surgical planning of the pelvic model for pelvic reconstruction [13]. Ead et al. used the symmetry of the pelvis to virtually reconstruct unilateral pelvic fractures [14]. To conduct this study, eight adult patients (five male and 3 female) with acute unilateral displaced pelvic fractures were used. CT scans were performed and converted into 3D models with the use of Mimics image processing software. The fractured hemipelvis was reflected across a sagittal plane and aligned with the intact hemipelvis which allows for the reconstruction of fractured parts [14].

Connection to Lower Back Pain

This study done by Al-Eisa et al. aimed to find a correlation between low back pain (LBP) and pelvic asymmetry [15]. The total number of subjects used was 113, 59 with no history of LBP (25 male and 34 female) along with 54 reported to have LBP (27 males and 27 females). To assess pelvic asymmetry, a measuring frame was used to obtain the width and height of the anterior and posterior superior iliac spines (points on the pelvic bone) of the subject's in standing position. To measure the pelvic asymmetry, measurements were taken for different points on the pelvic bone for each subject and the mean values from three sets of measurements were used to calculate a pelvic asymmetry ratio. From the data collected, it is possible to see that patients with LBP had much higher asymmetries of position and motion, meaning asymptomatic patients are most likely predisposed to LBP [15].

TORSO

About 2% to 4% of the population is affected by adolescent idiopathic scoliosis (AIS), and radiographs are a common way for researchers and clinicians to assess scoliosis [16]. However, consecutive visits with excessive radiation can increase the risk of cancer in young patients with AIS during growing years. A noninvasive method called surface topography (ST) is an alternative method for assessment of scoliosis, except this method requires markers to be applied by skilled operators which is time consuming and has the potential for errors. This novel method proposed is a three-dimensional analysis of ST data of patients with scoliosis. To conduct this study, 46 full torso scans of patients with AIS along with 5 healthy subjects were used. From the scans, the best plane of symmetry was determined, which allowed for the left and right sides to be mirrored and examined for deviations between the original torso and the reflection image. This allowed the creation of an easy to understand asymmetry map of each torso 16].

Torso Continued

In this study by Hill et al.,10 patients with adolescent idiopathic scoliosis (AIS) were used to assess their asymmetry through reflection and rotoinversion techniques [17]. For both methods, the process begins by taking Surface Topography (ST) scans to create three-dimensional images. For the first process, the best plane of symmetry is determined. From here the image is reflected across this plane and the distance between each sides cloud of points is calculated. The second process is very similar, the image is reflected along an arbitrary sagittal plane and rigidly transformed by the ’best fit’ function. From there, colour deviation maps are created and show the symmetry (or lack of) in each image. These methods require minimal time, expertise or training and accurately assess the symmetry of a 3D model [17].

Conclusion

Symmetry can be found in many different anatomical regions, and ways of measuring this symmetry varies. However, the most common ways to obtain symmetry include landmark based and closest point algorithms. These methods could be applied to the face, pelvis or torso when attempting to determine the symmetry of any of these regions. The findings in most of these papers will be used for future reference when planning plastic or reconstructive surgery. With the development of more computer-aided design software, 3D analysis of symmetry is more common and useful because of the 3D nature of bones. These methods use CT scans to develop 3D models of any bone, allowing them to more accurately and efficiently determine symmetry. The human body shows great bilateral symmetry, and the determination of asymmetry can be done in many ways, as explored in this literature review.

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Literature Cited

[1] M. M. Baclig, L. Westover, and S. Adeeb, "Categorizing three-dimensional symmetry using reflection, rotoinversion, and translation symmetry," Symmetry, vol. 11, no. 9, 2019, doi: 10.3390/sym11091132.

[2] M. Martini, A. Klausing, M. Messing-Jünger, and G. Lüchters, "The self-defining axis of symmetry: A new method to determine optimal symmetry and its application and limitation in craniofacial surgery," Journal of Cranio-Maxillofacial Surgery, vol. 45, no. 9, pp. 1558–1565, 2017, doi: 10.1016/j.jcms.2017.06.023.

[3] M. J. Cho et al., "Quantifying Normal Craniofacial Form and Baseline Craniofacial Asymmetry in the Pediatric Population," Plastic and reconstructive surgery, vol. 141, no. 3, pp. 380e–387e, 2018, doi: 10.1097/PRS.0000000000004114.

[4] R. M. Yáñez-Vico, A. Iglesias-Linares, D. Torres-Lagares, J. L. Gutiérrez-Pérez, and E. Solano-Reina, "Three-dimensional evaluation of craniofacial asymmetry: An analysis using computed tomography," Clinical Oral Investigations, vol. 15, no. 5, pp. 729–736, 2011, doi: 10.1007/s00784-010-0441-7.

[5] H. J. Kim, B. C. Kim, J. G. Kim, P. Zhengguo, S. H. Kang, and S. H. Lee, "Construction and validation of the midsagittal reference plane based on the skull base symmetry for three-dimensional cephalometric craniofacial analysis," Journal of Craniofacial Surgery, vol. 25, no. 2, pp. 338–342, 2014, doi: 10.1097/SCS.0000000000000380.

[6] G. Roumeliotis, R. Willing, M. Neuert, R. Ahluwalia, T. Jenkyn, and A. Yazdani, "Application of a Novel Semi-Automatic Technique for Determining the Bilateral Symmetry Plane of the Facial Skeleton of Normal Adult Males," Journal of Craniofacial Surgery, vol. 26, no. 6, pp. 1997–2001, 2015, doi: 10.1097/SCS.0000000000001937.

[7] M. Pinheiro et al., "A 3D cephalometric protocol for the accurate quantification of the craniofacial symmetry and facial growth," Journal of Biological Engineering, vol. 13, no. 1, pp. 1–11, 2019, doi: 10.1186/s13036-019-0171-6.

[8] L. di Angelo, P. di Stefano, L. Governi, A. Marzola, and Y. Volpe, "A robust and automatic method for the best symmetry plane detection of craniofacial skeletons," Symmetry, vol. 11, no. 2, pp. 1–14, 2019, doi: 10.3390/sym11020245.

[9] A. M. Launonen et al., "Craniofacial Asymmetry from One to Three Years of Age: A Prospective Cohort Study with 3D Imaging," Journal of Clinical Medicine, vol. 9, no. 1, p. 70, 2019, doi: 10.3390/jcm9010070.

[10] J. Damstra, Z. Fourie, M. de Wit, and Y. Ren, "A three-dimensional comparison of a morphometric and conventional cephalometric midsagittal planes for craniofacial asymmetry," Clinical Oral Investigations, vol. 16, no. 1, pp. 285–294, 2012, doi: 10.1007/s00784-011-0512-4.

[11] M. F. Barnes, "Efficacy study of the effect of a myofascial release treatment technique on obtaining pelvic symmetry," Journal of Bodywork and Movement Therapies, vol. 1, no. 5, pp. 289–296, 1997, doi: 10.1016/s1360-8592(97)80064-2.

[12] K. D. Ashwath Yegyan Kumar, Marwan El-Rich, Jacob Jaremko, "Symmetry of the Pelvis using Volume and Deviation Analysis," 22nd Congress of the European Society of Biomechanics, no. July, 2016, [Online]. Available: https://www.researchgate.net/publication/306241015_Symmetry_of_the_Pelvis_using_Volume_and_Deviation_Analysis.

[13] M. S. Ead, K. K. Duke, J. L. Jaremko, and L. Westover, "Investigation of pelvic symmetry using CAD software," Medical and Biological Engineering and Computing, vol. 58, no. 1, pp. 75–82, 2020, doi: 10.1007/s11517-019-02068-w.

[14] M. S. Ead, L. Westover, S. Polege, S. McClelland, J. L. Jaremko, and K. K. Duke, "Virtual reconstruction of unilateral pelvic fractures by using pelvic symmetry," International Journal of Computer Assisted Radiology and Surgery, vol. 15, no. 8, pp. 1267–1277, 2020, doi: 10.1007/s11548-020-02140-z.

[15] E. Al-Eisa, D. Egan, K. Deluzio, and R. Wassersug, "Effects of Pelvic Skeletal Asymmetry on Trunk Movement," Spine, vol. 31, no. 3, pp. E71–E79, 2006, doi: 10.1097/01.brs.0000197665.93559.04.

[16] A. Komeili, L. M. Westover, E. C. Parent, M. Moreau, M. El-Rich, and S. Adeeb, "Surface topography asymmetry maps categorizing external deformity in scoliosis," Spine Journal, vol. 14, no. 6, pp. 973-983.e2, 2014, doi: 10.1016/j.spinee.2013.09.032.

[17] S. Hill et al., "Assessing asymmetry using reflection and rotoinversion in biomedical engineering applications," Proceedings of the Institution of Mechanical Engineers, Part H: Journal of Engineering in Medicine, vol. 228, no. 5, pp. 523–529, 2014, doi: 10.1177/0954411914531115.