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Aortic Coarctation Diagnosis on Echocardiography Images

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Abstract

Aorta is the main artery that carries clean highly-oxygenated blood pumped by the heart. Aortic coarctation is a congenital heart disease that restricts blood flow in this artery and it is a condition that can be difficult to diagnose in the fetus or newborns. This difficulty stems from a narrow seperation occurring between the aorta and the ductus arteriosus, often near the origin of the left subclavicular artery. The ductus arteriosus usually closes spontaneously after birth, when aortic coarctation starts being detectable. Echocardiography is the preferred method of diagnosis of aortic coarctation in newborns, which is performed by the physician examining the image. Such diagnosis has proven to be a difficult with low success rates. The aim of this study is to measure aortic diameter of newborns using echocardiography image processing techniques for better, faster and more objective diagnosis of aortic coarctation.

Keywords: Aortic coarctation, echocardiography, image processing.

1. Introduction

Aortic coarctation (CoA) in newborns (the first 28 days [1]) exhibits itself as the narrowing of the aortic lumen making it difficult for blood flow from the heart to the upper body. Aortic coarctation can be a difficult to diagnose in the fetus or newborns. The difficulty in diagnosis stems from the existence of a vessel called the ductus arteriosus, a vascular connection that provides passage between the pulmonary artery and the aorta in the fetus, that helps maintain blood flow in the aorta. A narrowing occurs between the aorta and the ductus arteriosus, often near the origin of the left subclavicular artery. The ductus arteriosus usually closes spontaneously after birth, when aortic coarctation becomes detectable. Aortic coarctation is the most common congenital heart disease of ductal-dependent systemic circulation [2]. The neonatal period is characterized by changes in organ functions. The neonatal myocardium is less able to tolerate increased preload and has a lower response to increased post load. Therefore, early and accurate diagnosis of aortic coarctation is crucial for preventing acute deterioration of cardiac functions in newborns. Persistent ductus arteriosus (PDA) in the fetus and newborns can change the anatomy of the aortic lumen, making it difficult to evaluate the degree of narrowing of the aortic isthmus [2].

Symptoms of aortic coarctation vary depending on the degree of stenosis. In mild cases, there may be no symptoms. In moderate and severe cases, tiredness, shortness of breath, chest pain, dizziness, fainting and swelling in the legs may be observed [2]. In newborns, obstruction due to coarctation may occur a few days after birth and in rare cases it can be detected using pulse oximetry in newborn screening [3]. Recently, cardiac ultrasound has become a more commonly used test for early diagnosis of CoA, used to determine the extent and location of aortic narrowing. Advancements in cardiac ultrasound imaging technology have the potential to improve prenatal diagnosis of CoA [4].

Surgical intervention of CoA involves widening or repairing the stenosis in the aorta. This procedure is usually performed as open-heart surgery during infancy. In older children and adults, less invasive procedures such as stent placement or balloon dilation may also be used. Surgery is arguably the treatment of choice for native aortic coarctation in newborns. In older babies, balloon coarctoplasty also has good early and mid-term outcomes and acceptable reintervention rates [6]. Therefore, it is also considered as an alternative to open-heart surgery, especially in critically ill patients with high surgical risk [6]. The best approach to treat CoA in the pediatric population is a highly debated topic. However, stent implantation has been shown to result in shorter hospital stays and fewer acute complications compared to surgical repair or balloon angioplasty. Additionally, covered stents appear to be more protective than bare stents [7].

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Critical aortic coarctation can be fatal if left untreated. Therefore, it is important for infants with this condition to be diagnosed and treated rapidly after birth. People with aortic coarctation still need regular checkups throughout life. These checks help prevent the stenosis from progressing or complications from occurring [7]. Regardless of the treatment type, aortic coarctation is a disease that can be treated. However, it can be fatal if it is not diagnosed in a timely manner or if a false negative diagnosis occurs. Current diagnosis method requires: an echocardiography taken by a pediatric cardiologist, ductus arteriosus being closed at the time of imaging, and aorta diameter measurements made manually.

Recent studies from Scandinavia found that at least 50% of newborns with aortic coarctation were not diagnosed accurately within five days after birth [8]. In a study conducted in California, 27% of patients with aortic coarctation died before diagnosis at an average age of 17 days [8]. Ward *et al.* observed that infants with symptomatic aortic coarctation appeared between five and 14 days after birth. Coarctation can be detected by fetal echocardiography, but this method is generally used by specialists and is not intended for a wider spread general use [8].

Since medical images vary widely and has complexities due to different imaging modalities, image quality, patients, and other factors, it is difficult to create analytical solutions or simple equations to represent objects such as lesions and anatomical structures. Machine learning is a powerful tool that can address these differences and complexities in medical images. Machine learning algorithms are designed to learn from examples and represent data on their own allowing a potential for more objective, accurate and reliable results for diagnostic tasks in medical imaging. Machine learning is currently used in a variety of medical imaging applications for computer-aided diagnosis, image segmentation, tissue classification, pathology detection, and more [9, 10].

Marrow *et. al.* have investigated differences in aortic size between newborns with and without coarctation of the aorta. In comparison, they found that the aortic ring, the ring at the base of the aorta, was smaller in newborns with CoA than in healthy newborns. Their study also revealed that transverse aortic arch and isthmus parts of the aorta were narrower in newborns with CoA than in healthy babies [11].

In this project, to address the need for a better and timely diagnostic procedure for diagnosis of CoA in newborns, we aim to utilize image processing on echocardiography images for recognizing the aorta and measuring its diameter to detect any narrowing or widening when compared to healthy newborns' aorta dimensions. Such automated diagnosis has the potential for use in situations even when an expert interpreter of echocardiography images is not available for consulting, for example in the emergency rooms where time savings increase newborns' chances of survival. Additionally, this type of diagnosis will help minimizing subjectivity in measurements.

2. Methodology

This study was conducted by using the echocardiography images of healthy newborns for training and comparing them with the ones diagnosed with aortic coarctation. Images were also pre conditioned by basic image processing methods for facilitating of accurate detection of CoA. The method explained here was intended for a decision support system that includes the processes of identifying life-threatening aortic stenosis, making the necessary measurements for its treatment through a visual model, and determining non-standard values.

2.1. Ultrasound Images

Eechocardiography images of 55 healthy newborns and 4 newborns with aortic coarctation were obtained from Erzurum Atatürk University, Faculty of Medicine, Department of Pediatric Cardiology and Kastamonu Private Anadolu Hospital Neonatal Intensive Care Service after the related ethical and regulatory permissions were obtained. Number of images containing CoA patients were limited to 4 as it is a rare condition which presents challenges for higher number of samples collection.

2.2. Image Processing and Measurement Tool

We describe a decision support system that can help diagnosing CoA even at the emergency departments by utilizing a quick evaluation tool for echocardiography images of infants. First, the aortic vessel echocardiography images were introduced to a machine learning algorithm for training purposes. A software using CvZone and NumPy libraries on the Python-PyCharm platform over existing echocardiography images of healthy newborns was used. As a result, measurement system that can evaluate cardiac ultrasound images with different reference values were generated.

Once the echocardiography images were loaded, the software flow incorporates following steps of processing:

1. Scaling: Echocardiography images can have reference values of 6 cm or 8 cm. Thus, as a first step he appropriate reference values were entered to the software manually by the user for accurate scaling and diameter reporting.
2. Gray scale optimization: The image was transformed into a study-standardized and previously conditioned 8-bit grayscale image, which is optimized for clear visibility and identification of the aorta.
3. Gaussian Blur: A Gaussian blur that was designed to preserve the imaging device's theoretical resolution is applied to the image to reduce salt-and-pepper noise and pixelation degrading the appearance of cardiovascular structures. Thus, further improving the visibility of aorta.
4. Image segmentation: A section of the image where the overall heart structures were visible was segmented out of the complete image for further processing.
5. Feature detection: Using the segmented image, general features of the heart were marked manually by a trained professional for locating the area of interest (AOI).
6. Training: Images with marked features together with the acquisition parameters of the images were used for training the algorithm for three-dimensional appearance of the heart and aorta.
7. Detection of aorta diameter: In the final step, the algorithm detects a circular region using the Hough circle transform where the aorta region exists. Then, by changing the circular regions' radius using parameters withing the previously set minimum and maximum radii limits and step sensitivity, a resulting green circle was drawn on the original ultrasound image.

As a result, the software reports the measurement of the aorta diameter in millimeters (mm) or centimeters (cm) on the user interface. At the end of this process, the images with labelled aortas and related diameter measurements were saved in to a selected folder.

3. Results

All 59 echocardiography images obtained from newborns were used as inputs to the software tool for automated detection and reporting of the aorta diameter. For 55 healthy newborns, an average of 8,09±1,18 mm was reported, consistent with those previously reported [3, 8, 11]. On the other hand, the average of 4 CoA patients' diameter measurements reported by the software were lower at 2,83±0,55 mm, a statistically significant difference (unpaired T-test two-tailed P value = 0,001). Figure 1A, show an exemplary echo image and corresponding aorta diameter measurement of an infant (6,71 mm) reported as "healthy" by the software. Figure 1B show an exemplary echo image and corresponding aorta diameter measurement (2,12 mm) of a CoA patient infant reported as "not normal" by the software.

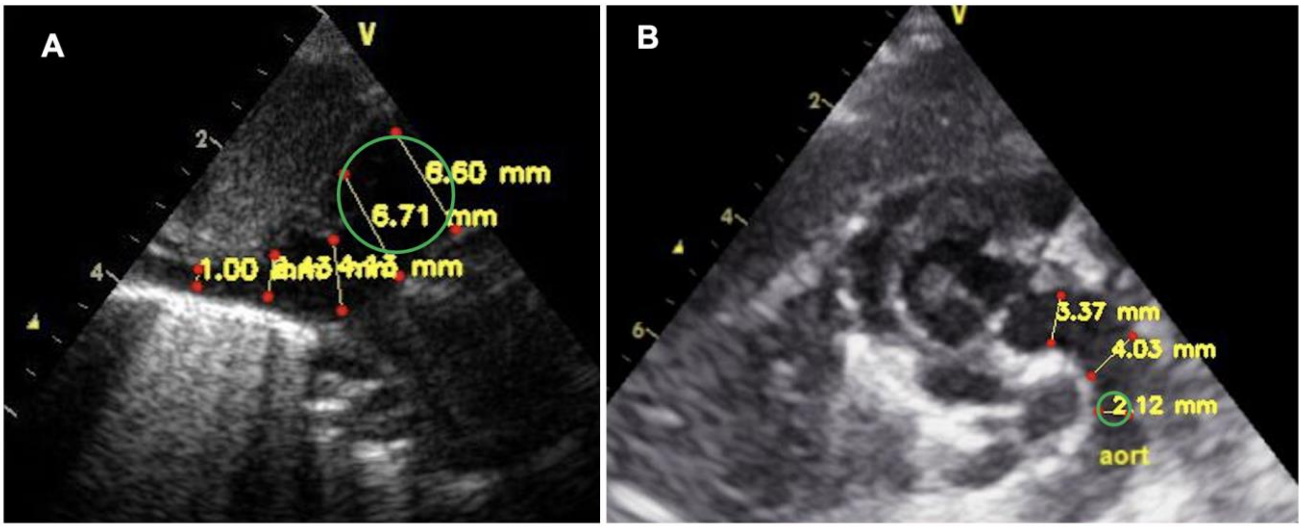

Figure 1. ***A.*** *Echo image of newborn aortic diameter measured at* 6,71 mm *mm by the software.* ***B.*** *Echo image of newborn aortic diameter measured at* 2,12 mm *mm by the software.*

Although with limited number of samples, due to difficulty of obtaining echo images of infants with CoA, this study demonstrated the feasibility of objectively diagnosing newborn CoA patients over a group 59 samples. Albeit the small sample size, such demonstration helps us understand the potential of machine learning based software development in medical imaging applications. This type of software solutions, after receiving required validations and experienced physician confirmations, could allow minimizing the undesired effects specialists being inaccessible at remote locations and hospitals with insufficient resources to get an alternative and objective diagnosis possibility. It also helps making more optimal intervention decisions by physicians.

4. Discussion

Specialists' CoA diagnosis success rates may vary depending on doctors' personal experience levels, evaluation consistency and perspectives, which inserts an undesired variability into diagnosis and treatment processes. Future machine learning studies can contribute mitigating problems that may stem from such inconsistencies and have potential for obtaining more objective and consistent measurements that can result in more accurate diagnoses with lower false negative or false positive rates. However, it is important to understand that these algorithms require a large amount of data to be accurate and effective. In this study, the small data size prevents us from drawing conclusive outcomes and demonstrating the full potential of our processing technique in medical ultrasound images. Nevertheless, even with limited data size we demonstrate its feasibility. In the future, we aim to increase the data entry to improve automated diagnosis potential.

In aortic coarctation, narrowing occurs between the aorta and the ductus arteriosus, usually near the origin of the left subclavicular artery. This is a situation in which we have a high detection rate when we image the part defined as the aortic arch. However, for now, the developed software can only evaluate transthoracic echocardiography images and take circular measurements. The measurement reliability was limited by the software's occasional section recognition issues, image acquisition angle related variances, and the fact that only one single section was being used. In the future, we aim to improve the software by defining the aortic arch and take measurements in cross-sections with high lateral sampling. Such improvements would help reducing the possibility of an aorta narrowing being overlooked by the algorithm [12]. Machine learning models can identify complex patterns and trends that may escape human eyes, which could help diagnose aortic stenosis more accurately and minimize misdiagnoses while also allowing cost savings.

In summary, albeit the small data size, our software was able to recognize the transthoracic echocardiography images and detect aorta narrowing. With improvements like introduction of aortic arch and larger data sets, the presented software has the potential for higher accuracy results and better performance in a bigger variety of image angles and qualities. Consequently, it can help faster, more accurate and less costly diagnosis of infant CoA.

Declaration of Interest

The authors declare that there is no conflict of interest.

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Author Contributions

Yaren Engin carried out the image collection, image processing software development, measurements and organizing of the results shown in this study. Omer Pars Kocaoglu defined the project criteria, interpreted results and wrote the manuscript.

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