A step towards measuring the fetal head circumference with the use of obstetric ultrasound in a low resource setting

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ABSTRACT

Worldwide, 99% of all maternal deaths occur in low-resource countries. Ultrasound imaging can be used to detect maternal risk factors, but requires a well-trained sonographer to obtain the biometric parameters of the fetus. One of the most important biometric parameters is the fetal Head Circumference (HC). The HC can be used to estimate the Gestational Age (GA) and assess the growth of the fetus. In this paper we propose a method to estimate the fetal HC with the use of the Obstetric Sweep Protocol (OSP). With the OSP the abdomen of pregnant women is imaged with the use of sweeps. These sweeps can be taught to somebody without any prior knowledge of ultrasound within a day. Both the OSP and the standard two-dimensional ultrasound image for HC assessment were acquired by an experienced gynecologist from fifty pregnant women in St. Luke's Hospital in Wolisso, Ethiopia. The reference HC from the standard two-dimensional ultrasound image was compared to both the manually measured HC and the automatically measured HC from the OSP data. The median difference between the estimated GA from the manual measured HC using the OSP and the reference standard was -1.1 days (Median Absolute Deviation (MAD) 7.7 days). The median difference between the estimated GA from the automatically measured HC using the OSP and the reference standard was -6.2 days (MAD 8.6 days). Therefore, it can be concluded that it is possible to estimate the fetal GA with simple obstetric sweeps with a deviation of only one week.

Keywords: Fetal head circumference, prenatal imaging, ultrasound imaging, obstetric sweep protocol, low-resource

1. DESCRIPTION OF PURPOSE

Ultrasound imaging is widely used for prenatal imaging to detect maternal risk factors. During an echoscopic examination the sonographer measures several biometric parameters of the fetus. One of the most important parameters is the fetal Head Circumference (HC). The HC can be used to estimate the Gestational Age (GA) and assess the growth of the fetus. A sonographer needs to acquire the correct frame and manually measure the HC, which requires both medical knowledge of the anatomy and technical knowledge of the ultrasound device. There is a severe shortage of sonographers with sufficient skills in low resource settings. Therefore, Destigter et al.[1] proposed the Obstetric Sweep Protocol (OSP), which makes it possible to image the abdomen of pregnant women with the use of sweeps, where the ultrasound probe is moved slowly over the abdomen of pregnant women from a predefined start and end point. These sweeps can be taught to somebody without any prior knowledge of ultrasound within a day. Unfortunately, it was not evaluated if the biometric parameters of the fetus could be extracted from the OSP. In this study, the OSP together with the standard two-dimensional (2D) ultrasound image of the fetal HC were obtained from fifty pregnant women in St. Luke's Hospital in Wolisso, Ethiopia, by

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an experienced gynecologist. The HC was manually measured in the sweep data and compared to the reference HC that was obtained from the 2D ultrasound image. Furthermore the HC was automatically measured using the OSP data with the use of a Computer Aided Detection (CAD) system that we especially developed for this purpose. These results were also compared to the reference HC to evaluate if it is possible to automatically obtain the HC from sweep data.

2. METHODS

The first step to investigate whether it is possible to estimate the HC with the OSP was the acquisition of the OSP together with the standard 2D ultrasound image that could be used as a reference standard. Second, the HC was manually measured using the OSP data. Third, the HC was automatically measured using the OSP data with the use of a CAD system. Last, the results were evaluated by comparing both the manually and automatically measured HC to the reference HC that was measured in the standard 2D ultrasound image.

2.1 Data acquisition

The data for this study was acquired in St. Lukes Catholic Hospital and College of Nursing and Midwifery, Wolisso, Ethiopia. This study was approved by the local ethics committee. A well-trained sonographer first performed the usual diagnostic echoscopic examination which also included the measurement of the fetal HC. This 2D ultrasound image of the HC was used as a reference standard. After the echoscopic examination the sonographer performed the OSP. The OSP was introduced by Destigter et al.[1] The OSP consists of five sweeps (six in the third trimester) over the abdomen of the pregnant women. In this study, the Samsung Medison SonoAce R3 (Korea) was used to perform the OSP with a frame rate of twenty frames per second. The sonographer was asked to obtain between 80 and 120 frames per sweep. Saving one cine-loop of one-hundred frames took around one minute, so to prevent a delay in the clinical work flow it was decided to only obtain the three transverse sweeps of the OSP. The transverse sweeps were obtained from the pubic bone to the breast bone as shown in 1. The imaging depth was set to 12 cm.

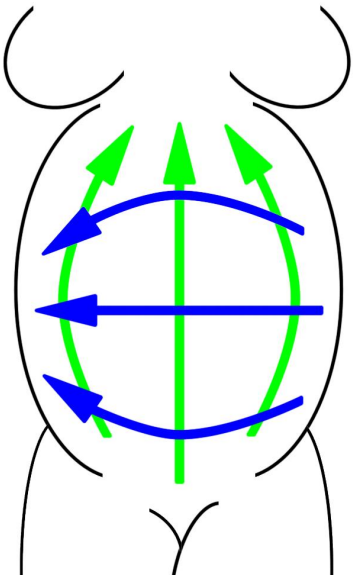

Figure 1. The sweeps of the Obstetric Sweep Protocol proposed by DeStigter et al. The three transverse sweeps are obtained from the pubic bone to the breast bone and are shown in green. The three longitudinal sweeps are obtained from the left side to the right side of the patient and are shown in blue.

2.2 Manually measuring the HC using the OSP data

Manually measuring the HC using the OSP data consisted of four steps. First, the sweep on which the fetal head was best visible was selected. Second, the frame within this sweep was selected on which the fetal head was best visible. Third, an ellipse was manually drawn to delineate the fetal HC. Last, the HC was computed from the delineated ellipse, using the pixel size of the ultrasound image. During the process of manually delineating the HC using the OSP, the reader was blinded for the 2D reference standard.

2.3 Automatically measuring the HC using the OSP data

The CAD system consisted of four steps. First, Haar-like features[2] were extracted from the image to detect the pixels in the image that belong to the fetal skull using a pixel classifier. Second, Hough transform[3] was used to detect the center of the fetal skull that was detected by the pixel classifier. Third, a dynamic programming algorithm[4] was used to extract the outside of the fetal skull. Last, the HC was obtained by fitting an ellipse through the result of the dynamic programming algorithm. One classifier per trimester was computed to make a robust measurement of the HC possible. The best classifier was automatically chosen by taking the ellipse that has the highest median pixel value in the pixel classifier output. The used CAD system was developed using 2D ultrasound images of the HC images made with the GE Voluson E8 or GE Voluson 730 ultrasound device from the Radboud University Medical Center. So not only the acquisition protocol, but also the image quality was different from the OSP data that was used in this study.

2.4 Evaluation

The median difference between the reference HC measured from the 2D ultrasound image and both the manual and automated measured HC from the OSP were computed. Furthermore, the Median Absolute Deviation (MAD) was computed according to Equation (1), where X_i were the differences between the reference HC and the HC measured from the OSP data.

$$MAD = median(|X_i - median(X_i)|)\,, \tag{1}$$

The GA of the fetus was determined from the HC with the use of the curve of Hadlock.[5] The GA was computed for each measured HC that fell within the curve of Hadlock. The difference in GA between the reference standard and the GA obtained from the OSP data were evaluated using both the median and MAD.

The Spearman's correlation coefficient between the measurements from the reference and the OSP for both the HC and the GA were computed using SPSS (version 20.0).

3. RESULTS

Figure 2 shows two scatter plots that visualize the comparison between the reference HC with the manual measured HC from the sweep (the top image) and the automated measured HC from the sweep (the bottom image). The transparency of the points in the scatter plot indicate the percentage of the manually annotated HC that falls within the Field Of View (FOV) of the ultrasound image. Black means that 100% of the manually annotated HC falls within the FOV of the image and white means that 60% of the manually annotated HC falls withing the FOV of the image.

Table 1 shows the results of the evaluation between the 2D reference and both the manually and automatically measured HC from the OSP. The results of Table 1 show that four data points were excluded from evaluation of the GA. The HC of these fetuses was larger than the larges reported value of the Hadlock curve, so therefore GA could not be computed for these four fetuses.

The left column of Figure 3 shows the result with the smallest difference between the manually measured HC using the OSP and the reference HC, the middle column of Figure 3 shows the result with the largest difference between the manually measured HC using the OSP and the reference HC and the right column of Figure 3 shows the result with the largest difference between the automatically measured HC using the OSP and the reference HC.

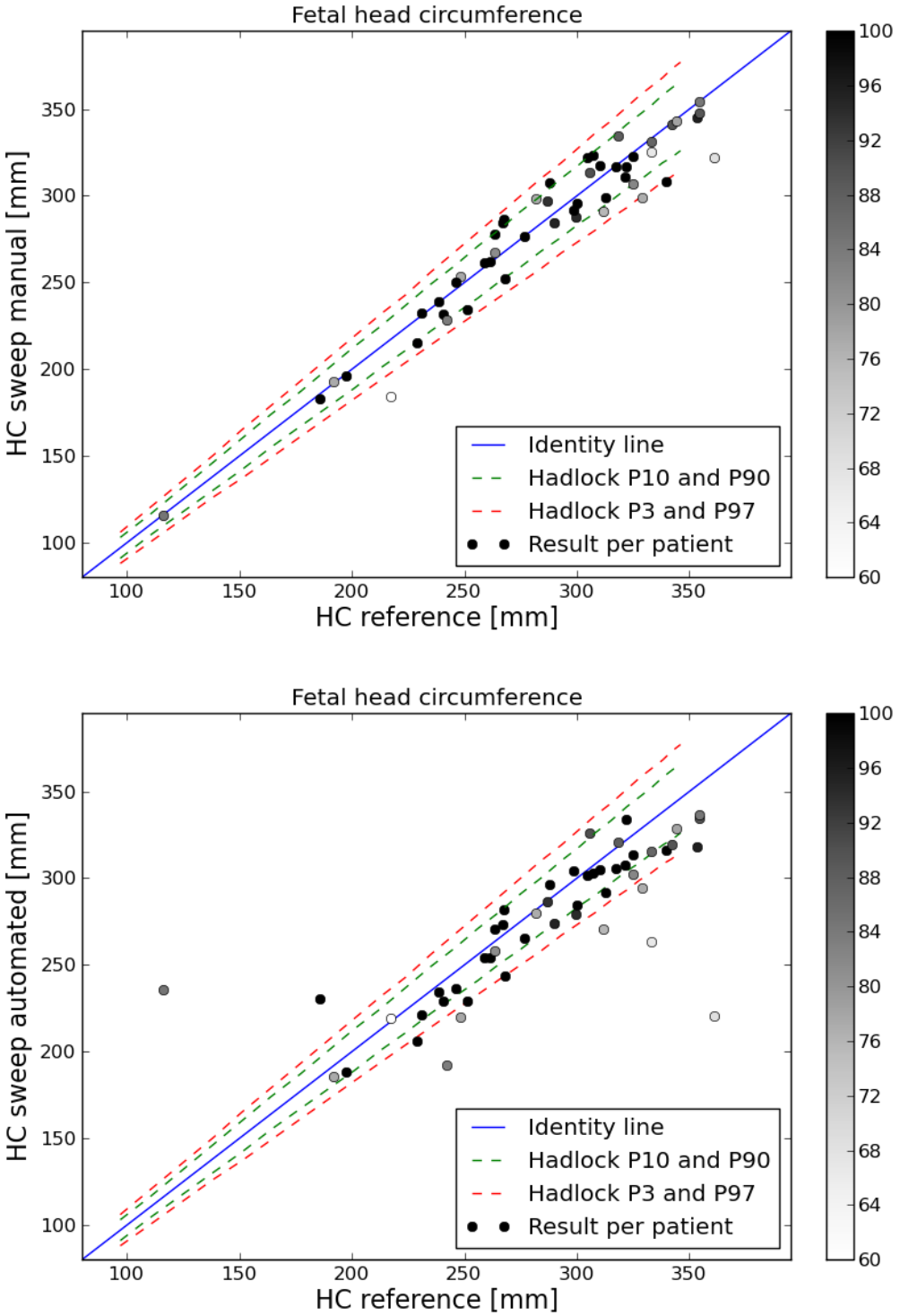

Figure 2. Scatterplot of with the reference HC compared to the HC measured using the OSP. Top, the manually measured HC using the OSP. Bottom, the automated measured HC using the OSP. See text for an explanation of the transparency of the points.

Table 1. Result of the evaluation between the 2D reference and the OSP

Reference compared to	Median difference HC (MAD)	Spearman's correlation HC	Median difference GA (MAD)	Spearman's correlation GA
OSP manually	-1.2 mm (7.2 mm)†	$\rho = 0.941$†*	-1.1 days (7.7 days)‡	$\rho = 0.936$‡*
OSP automatically	-11.1 mm (10.2 mm)†	$\rho = 0.812$†*	-6.2 days (8.6 days)‡	$\rho = 0.883$‡*

†$N = 50$, ‡$N = 46$, *$p < 0.001$

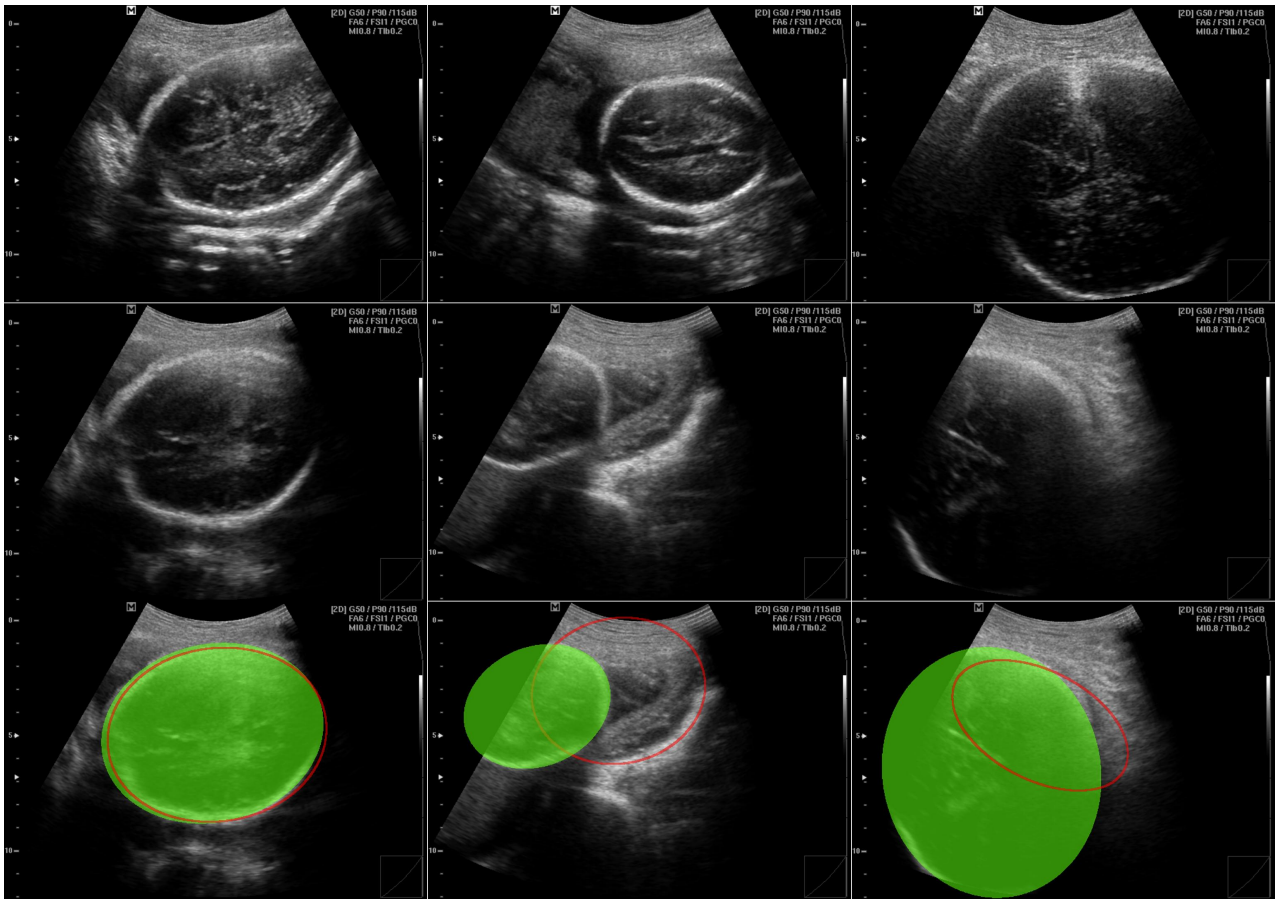

Figure 3. From top to bottom: 2D reference image, selected frame from the OSP, selected frame from the OSP with overlay of manually measured HC in green and automatically measured HC in red. From left to right: result with the smallest difference between the manually measured HC from the sweep and the reference HC, result with the largest difference between the manually measured HC from the sweep and the reference HC, result with the largest difference between the automatically measured HC from the sweep and the reference HC.

4. DISCUSSION

The results of Table 1 show that it is possible to manually estimate the HC with the use of the OSP with a median difference of -1.2 mm (MAD = 7.2 mm), which is highly correlated with the reference ($\rho = 0.941$). These measured HC result in a median GA difference of -1.1 days (MAD = 7.7 days), which is also highly correlated with the reference ($\rho = 0.936$). Most of the measured GAs fall within the P3-P93 range of the Hadlock curve.

The result with the largest difference between the manually measured HC using the OSP and the reference HC is shown in middle column of Figure 3. During the acquisition of the OSP this fetus moved during the saving

of the sweeps. Therefore the fetal skull did not fall within the FOV of the ultrasound image in any sweep. This problem could be reduced in the future by using a different ultrasound device that is able to record all sweeps after each other. This would reduce the chance that the fetus will move during the acquisition of the OSP. This would also facilitate the acquisition of the longitudinal sweeps of the OSP, without delaying the clinical work flow. The longitudinal sweeps will be better suited to estimate the HC, especially when the fetus lies in shoulder presentation.

Table 1 show that it is possible to automatically estimate the HC with the use of the OSP with a median GA difference of -6.2 days (MAD = 8.6 days), which is highly correlated with the reference ($\rho = 0.883$). The difference between the automated measured HC using the OSP and the reference is larger compared to the manually measured HC using the OSP. This is mainly caused by the fact that the fetal head sometimes falls partly outside the FOV of the ultrasound image. When this happens, the automated system fails to accurately measure the HC. This is visible in Figure 2, where it can be seen that the brighter points have a larger difference compared to the darker points. The result with the largest difference between the automatically measured HC using the OSP and the reference HC is shown in right column of Figure 3. In this example it can be clearly seen that a part of the fetal skull is located at a depth larger than 12cm. The CAD system is therefore not able to detect the bottom part of the fetal skull.

The estimated HC using the OSP could be improved in the future, by combining multiple frames to give an better estimation of the HC. Furthermore, the imaging depth of the ultrasound device should be increased to 15 cm, because with a depth of 12 cm it sometimes happens that a part of the fetal head is located at a larger depth.

In this work the frame on which the fetal head was best visible was manually selected. Future work includes develoment of a method to automatically detect the frames within the sweep data that contain the fetal head. This would fully automate HC measurements using the OSP.

5. CONCLUSION

We have presented a method to estimate the fetal HC with the use of the OSP. The OSP can be taught to somebody without any prior knowledge of ultrasound within a day. The results show that it is possible to estimate the GA of the fetus with a MAD of 7.7 days. It is also possible to automatically estimate the GA of the fetus with a MAD of 8.6 days, which could be very helpfull in a low-resource setting.

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