Introduction

The human fetus undergoes rapid changes in every gestational week (GW). The fetus is to be monitored by an obstetrician for its healthy growth. An important organ that is to be monitored is the fetal brain. Fetal brain starts developing from the 3rd GW and continue to grow in its shape and structure [1]. Some of the abnormalities that may occur in the central nervous system (CNS) in the early stages are encephalocele, anencephaly, hydrocephalus and microcephaly [2]. To understand the pathology and structure of the fetus, non-invasive imaging techniques such as ultrasound (US) and magnetic resonance imaging (MRI) are used. MRI is more suitable to image soft tissues such as brain and also gives a high contrast image. Identification of brain abnormalities helps to make informed decisions like termination of pregnancy (TOP) or in utero fetal death (IUFD) [3]. Votino et al. [3] have estimated the brain volume using MRI and weight using autopsy of the fetal brain. Estimation of fetal brain at different GW helps to identify normal and abnormal brain growth [4,5]. Estimating the brain volume through MR imaging has become an accepted technique [6,7]. In this paper, we propose a method to estimate the fetal brain volume from MRI of human fetus in the range of 20-38 GW by extracting the brain portion manually by an expert.
Materials Used

We used twenty volumes of retrospective T2-weighted single-shot fast spin echo (SSFSE) MRI collected from Sri Ramachandra Medical University and Hospital, Chennai, India. Ethical approval was granted by the Ethical Committee (ethics no. IEC-NI/14/OCT/43/65) of the same University. The datasets were imaged between 20 and 38 GW. Brain portion in all the volumes were manually segmented by a medical expert specialized in the fetal brain anatomy and are used for estimating the brain volume. The details of the dataset are given in Table 1. The data sets pertain to different subjects. This set was arranged to cover range of 20-38 GW period to form 12 volumes from the 20 sets. To estimate the fetal brain volume, we make use of the manually segmented fetal brain images. Fetal brain area is calculated for every MRI slice in the data set. An MR imaging volume contains collection of slices. Each slice displays an area of anatomy as the field of view (FOV). The FOV is divided into voxels. Every pixel of an MR image corresponds to a voxel, a volume element, whose value represents the tissue and MR signal, respectively. The volume of a voxel depends on MR imaging parameters, i.e. slice thickness (ST) and pixel spacing (Figure 1a). The physical thickness is specified in the parameters embedded in the MR image. Between two slices there will be a gap called inter slice gap (ISG) (Figure 1b).

Table 1: Details of retrospective T2-w fetal image.

| No. | GW   | Flip Angle | Slice Thickness (mm) | Slice gap (mm) | TR (ms) | TE (ms) | FoV (mm) |
|-----|------|------------|----------------------|----------------|---------|---------|----------|
| 1   | 20-21| 170        | 4                    | 4              | 850     | 86      | 188x280  |
| 2   | 20-21| 170        | 3.5                  | 3.5            | 1350    | 89      | 280      |
| 3   | 20   | 170        | 3.5                  | 3.5            | 800     | 89      | 270      |
| 4   | 29   | 90         | 4.5                  | 5              | 718     | 92      | 350      |
| 5   | 36   | 170        | 3.5                  | 3.5            | 1790    | 89      | 270      |
| 6   | 31   | 90         | 4.5                  | 4.8            | 473     | 91      | 360      |
| 7   | 29   | 170        | 4                    | 4.2            | 1350    | 91      | 300      |
| 8   | 27   | 90         | 5                    | 5.2            | 642     | 93      | 350      |
| 9   | 26   | 170        | 4.5                  | 4.5            | 700     | 89      | 280      |
| 10  | 23   | 170        | 4                    | 4.2            | 1350    | 91      | 320      |
| 11  | 29   | 170        | 4                    | 4.2            | 1350    | 91      | 300      |
| 12  | 33   | 90         | 4                    | 4              | 1062    | 88      | 320      |
| 13  | 20-21| 170        | 5                    | 5.5            | 1350    | 91      | 320      |
| 14  | 35-36| 170        | 4                    | 4              | 1350    | 91      | 300      |
| 15  | 38   | 90         | 4                    | 4.5            | 676     | 88      | 400      |
| 16  | 28-29| 170        | 4                    | 4.2            | 1350    | 91      | 280      |
| 17  | 31   | 90         | 3.5                  | 3.7            | 709     | 90      | 420      |
| 18  | 32-33| 160        | 3                    | 3              | 900     | 89      | 279x350  |
| 19  | 22-23| 160        | 3.5                  | 3.9            | 1000    | 85      | 350x279  |
| 20  | 35-36| 90         | 4                    | 4.5            | 695     | 92      | 420      |

Figure 2: Flowchart of the proposed method.
Method

The proposed method includes computing fetal brain area in each slice and estimating volume of fetal brain. The flowchart of the proposed method is shown in Figure 2.

Computing Area of Fetal Brain in Each Slice

For each segmented fetal brain from MRI slice, a binary mask is obtained. The pixels which have the intensity values greater than zero are assigned to one (white) and the rest of the pixels are assigned a zero value (black). The area is computed by counting the white pixels. In order to compute the area of the fetal brain in a slice, first the area of each pixel is computed in cm². This is done by reading the pixel spacing tag from the DICOM header of the corresponding MRI slice. The pixel spacing tag represents the spacing between the centers of any two adjacent pixels [8]. Half the length of the pixel spacing represents half the length of a pixel and the other half represents half the length of the adjacent pixel. Assuming that all the pixels in the image have the same length in both x and y direction, the pixel spacing (in mm) is equal to the pixel length. The area of any pixel is computed as:

\[
\text{Area of pixel} = \left( \frac{\text{pixelspacing}}{10} \right)^2 \text{cm}^2
\]  

Figure 3 shows that the pixel spacing is equal to the pixel length.

The area of the brain in the \( i^{th} \) slice is computed as:

\[
A_i = \text{Area of pixel} \times N_w \tag{2}
\]

where, \( N_w \) is the total number of white pixel in the slice. This process is repeated for all the slices in that volume.

Computing Fetal Brain Volume

The brain volume is computed by multiplying the area and slice thickness (ST). While acquiring the images, a physical gap is left in between two slices and is measured by inter slice gap (ISG). It is assumed that the area of the brain in the ISG is the average of the two adjacent slices. The ST and ISG are obtained by reading the header of DICOM images. The fetal brain volume \( BV \) is computed as:

\[
BV = \sum_{i=1}^{N-1} A_i \times (ST + ISG) + A_N \times ST mL \tag{3}
\]

where, \( N \) is the total number of slices in the volume and \( A_i \) represents the area of the fetal brain in the \( i^{th} \) slice, and \( A_N \) is the \( N^{th} \) slice.

Results and Discussion

The computed values of BV for 12 different gestational weeks are given in Table 2.

Table 2: Computed Fetal brain volume BV (mL).

| Vol Label | GW (weeks) | BV in mL |
|-----------|------------|----------|
| 1         | 20         | 66.84    |
| 2         | 21         | 75.2     |
| 3         | 22         | 81.3     |
| 4         | 23         | 90.1     |
| 5         | 26         | 112.1    |
| 6         | 27         | 117.4    |
| 7         | 29         | 132.87   |
| 8         | 31         | 145.65   |
| 9         | 32         | 158.27   |
| 10        | 33         | 201.6    |
| 11        | 36         | 320.2    |
| 12        | 38         | 439.17   |

Conclusion

We have developed a method to estimate the fetal brain volume from hand segmented brain portion from the MRI of human fetus. The fetal brain volumes at different gestational week were estimated. We found that the brain volume increases almost linearly till 32 GW and thereafter at a higher rate. It is 67 mL at 20 GW, 114 mL at 26 GW and 438 mL at 38 GW.

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