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# CORRELATION OF FETAL BLADDER DIMENSIONS WITH GESTATIONAL AGE AND AMNIOTIC FLUID INDEX IN THIRD TRIMESTER

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**Keywords:**

*Fetal bladder volume, Amniotic fluid index, Gestational age, Third trimester, Ultrasound, Antenatal assessment*

**Abstract**

***Background:***

*This study investigates the relationship between fetal bladder dimensions, gestational age, and amniotic fluid index (AFI) during the third trimester of pregnancy. The fetal bladder plays a key role in assessing renal function and contributes significantly to amniotic fluid volume, which is vital for fetal lung development and overall growth. Correlating bladder volume improves interpretation.*

***Objective:***

*To assess fetal bladder dimensions and their correlation with gestational age and amniotic fluid index during the third trimester of pregnancy.*

***Methodology:***

*A cross-sectional study was conducted over four months at the UOL Ultrasound Clinic, Green Town. A total of 150 third-trimester pregnant women fulfilling the inclusion criteria were selected through convenient sampling. Ultrasound examinations were performed using a Toshiba Aplio 300 machine equipped with a 3–5 MHz convex transducer.*

***Results:***

*The study population had a mean gestational age of 31.77 ± 3.28 weeks and a mean maternal age of 26.61 ± 5.06 years. Fetal bladder volume showed a significant positive correlation with gestational age ($p < 0.001$), indicating progressive bladder enlargement with advancing gestation. The correlation between bladder volume and AFI was not statistically significant ($p > 0.05$). Maternal age and*

*other biometric parameters also showed no significant associations ($p > 0.05$).*

***Conclusion:***

*Fetal bladder volume increases significantly with gestational age during the third trimester, reflecting normal fetal renal development and urinary function. However, no significant correlation was observed between bladder volume and AFI, suggesting independent regulation of these parameters.*

## INTRODUCTION

### CHAPTER 1

The fetal bladder is usually identifiable in the pelvic region by 11–12 weeks of gestation, and if it remains absent beyond 15 weeks, this is considered abnormal. Fetal urine formation begins around 8–10 weeks. Prior to this period, the amniotic fluid mainly originates from the passive diffusion of fetal blood through the still-permeable fetal skin. Because of this early physiology, oligohydramnios does not typically appear before 10 weeks of pregnancy (Yiee & Wilcox, 2008). The fetal urinary bladder, often referred to as the bladder bubble, appears as an anechoic cyst on ultrasound in most fetuses from 12 to 13 weeks of gestation. Bladder size is determined by measuring the longitudinal bladder diameter from the superior to the inferior aspect in the sagittal plane. Age-related reference charts help ensure accurate assessment of bladder size. Normally, the fetal bladder diameter should be less than 7 mm in the first trimester, under 30 mm in the second trimester, and not more than 60 mm during the third trimester. Similarly, the bladder wall thickness should consistently measure below 2 mm throughout pregnancy. A well-filled urinary bladder is a key indicator of kidney function. Beyond the first trimester, fetal urine production becomes the primary source of amniotic fluid, which is essential for proper lung maturation.Therefore, assessing amniotic fluid volume alongside fetal bladder volume is essential. The sagittal plane is the preferred orientation for measuring bladder diameter (Whittaker,J.L.,2009).

In the coronal section, both the stomach and bladder bubble can be seen within the same plane.if the bladder appears small during the first trimester, color Doppler imaging can help by outlining the umbilical arteries that run on both sides of it. In the later stages of pregnancy the second and third trimesters the fetal bladder typically goes through filling and emptying cycles every 25–30 minutes, while these cycles occur even more frequently earlier in pregnancy. If the bladder bubble is not initially visible, repeating the ultrasound after an appropriate interval may improve visualization (Gupta s.,et al.2025).

Amniotic fluid (AF) is the cushioning liquid that surrounds the fetus inside the amniotic sac. It originates early in pregnancy as a fluid-filled space near the time of implantation, before the embryo can be visualized. This fluid is essential for fetal protection, growth, and various diagnostic assessments. Abnormalities in its volume can occur: anhydramnios refers to an almost complete absence of fluid, oligohydramnios indicates a reduced amount, and polyhydramnios describes an excessive accumulation. There is a possibility of having polyhydramnios due to having fluid formation being high or having the excess fluid not being absorbed fully in the body. Higher risks of loss of the fetus that is in the womb are associated with levels of amniotic fluid that are either high or low. Defects in the structural or functional properties of the fetus in the womb, the stage of the pregnancy, the condition of the membranes, and the water interactions through the placenta and the amnion are complexities that define the amniotic fluid levels (Agwu,E.J.,et al.2016).

To assist with fluid volume in amniotic fluid (AFV) estimation, a number of techniques have been designed and put in place. Measuring the maximum vertical pocket (MVP) technique, a method of assessing amniotic fluid that is the most common and useful in detecting cases of oligohydramnios. The measurement of the deepest vertical pocket of fluid that is not obstructed by fetal limbs or the umbilical cord is what is referred to in this technique. 2cm is what is most considered the lower limit of normal in most clinical settings and a low value is associated with having oligohydramnios, Another method referred to is the four-quadrant technique, that is where the volume of the amniotic fluid is estimated by summing the fluid that is contained in the four uterine quadrant . this provide the total amniotic fluid index (Rashid, S.Q.2013).

However, studies allocate the single deepest vertical pocket (SDVP) technique as the superior option for routine fetal surveillance. Studies demonstrate that the Amniotic Fluid Index (AFI) also quantifies more pregnancies as oligohydramnios, which increases the number of labors that are induced. Nevertheless, those interventions do not result in better neonatal outcomes. That shows the importance in reviewing and benchmarking the discrimination of both methods. As AFI seems to provoke unnecessary clinical actions without value, SDVP is more appreciated as the gold standard for clinical judgements on the volumetric assessment of amniotic fluid. It is preferable to harmonise the assessment of the fetus as one single, clinically approved, and standard method (Nabhan & Abdelmoula, 2008).

Amniotic fluid is essential for fetal health. This fluid aids in anatomical development, growth, and lung maturation while safeguarding the fetus from trauma. Sufficient fluid is crucial for desirable outcomes and for the fetus to develop properly. Unfortunately, the normal reference ranges for amniotic fluid volume (AFV) relative to the weeks in gestation are still inadequately defined. This leads to difficulties in recognizing abnormal values (Coombe-Patterson,J.2017).

This review concludes that while there are several sonographic techniques for measuring amniotic fluid volume, no specific technique is completely correct in all situations. There's proof, however, to support the theory that there ought to be an established method to measuring AFV, as a consistent and precise measurement will lower the risks of adverse outcomes that negatively affect a fetus, as well as the morbidity and mortality rates that are a result of AFV irregularities. The review focuses on the most reliable and useful techniques that most measurement systems can be adopted to routine antenatal care (evidence-based) and can dramatically reduce the risks related to a fetus in AFV anomalies (Coombe-Patterson,J.2017).

It is critical to determine amniotic fluid volume (AFV) for prenatal care and is even more significant in high-risk pregnancies. Historically, techniques like dye-dilution and direct measurement in the operating room during a Cesarean section were all, but optimal as they were invasive, labor intensive, and required specialized lab resources. Due to these limitations, the assessment of AFV through ultrasound rapidly gained popularity by employing the single deepest pocket (SDP) technique and the amniotic fluid index (AFI) measurement. The SDP is part of the biophysical profile (BPP) and the AFI is paired with a non-stress test (NST) in the modified BPP. Both techniques have been thoroughly studied and analyzed (Magann et al., 2007).

Before 1987, the SDP method was the primary sonographic technique for AFV assessment. In that year, the Amniotic Fluid Index (AFI) was first applied in a study on post-term pregnancies, and later research helped establish its broad clinical use. After Moore's study indicated that AFI was a better predictor of oligohydramnios than the single deepest pocket (SDP) method, AFI largely supplanted SDP in routine practice, although SDP continued to be used within the biophysical profile (BPP). However, the claimed superiority of AFI went unchallenged for more than a decade, despite methodological limitations in the original study, where AFI was both the endpoint and the comparison standard. Subsequent studies comparing AFI and SDP with actual

amniotic fluid volumes found that neither method reliably reflects true abnormalities in amniotic fluid volume (Magann et al., 2007).

Since the early 1960s, ultrasonography has played a fundamental role in the practice of obstetrics and gynecology. Over time, ultrasound machines have become smaller while producing higher quality images. Modern imaging now ranges from portable, laptop-based devices to large, Highend ultrasound systems (HSUM) that feature power and color Doppler, 3D imaging, and advanced software capabilities. These high-end systems require specialized maintenance, careful handling, and a stable power supply. In contrast, pocket-sized ultrasound machines (PUMs) offer the advantage of performing basic bedside investigations. Since the late 1970s, PUMs have shown clinical value in cardiology, internal medicine, and obstetrics, sometimes altering initial diagnoses in up to 20% of patients with minimal additional time. In obstetric practice, pocketsized ultrasound machines (PUMs) can help evaluate placental position, fetal presentation and number, amniotic fluid volume, and fetal growth, offering potential benefits for patient care, particularly in rural or resource-limited areas. This study was designed to compare the effectiveness of a PUM with that of a high-specification ultrasound machine (HSUM) for routine third-trimester antenatal scans (Galjaard et al., 2014).

A study was conducted to determine whether the amniotic fluid index (AFI) or the single deepest pocket (SDP) provides a more accurate estimation of amniotic fluid volume. Both methods were compared against amniotic fluid volumes measured directly or using dye-based techniques. A PubMed search covering 1990 to 2006 was performed using keywords such as “single deepest pocket,” “largest vertical pocket,” “maximum vertical pocket,” or “2×1 pocket” combined with “amniotic fluid index.” A total of 1,219 studies on SDP and 4,378 papers on AFI were found during the search, but only 20 studies considered both techniques. Only 6 studies directly compared measurement of fluid volumes with AFI and SDP, finding that neither SDP nor AFI were able to accurately identify cases of fluid abnormality and that neither of the methods were better. However, AFI did identify oligohydramnios in significantly more cases than SDP did, but there was no better outcome in the pregnancies than in the SDP group. Due to these findings, this study suggested the use of SDP rather than AFI for the estimation of amniotic fluid Volume ( Magann et al., 2007).

Fetal development and pregnancy outcomes are influenced by the amount of amniotic fluid surrounding the baby. Though there isn’t enough data correlating the ages of the gestation with the fetal bladder dimensions and the available volume of amniotic fluid (AFV), specific liquid volumes still allow differing diagnoses and thee targeted treatment of conditions like oligohydramnios and polyhydramnios. There are many strategies to assess the volume of amniotic fluid during pregnancy. However, the most precise methods are still unclear. The Amniotic Fluid Index (AFI), created by Phelan and his colleagues in the year of 1987, partitions the uterus in to four quadrants and records the largest vertical fluid pocket in each quadrant. The total measurements are averaged out to estimate total volume of fluid. Correct measurement techniques must be applied most especially with the ultrasound equipment in order to record the most reliable results. For example, the ultrasound device must be perpendicular to the coronal plane and the most unobstructed fluid pocket has to be recorded. Each measurement must be 2 cm wide and 1 cm tall to be counted AFI measurements are typically performed after 25 weeks of gestation, with normal values ranging from 5 to 24 cm. Values of 5 cm or less indicate oligohydramnios, while measurements above 24 cm suggest polyhydramnios. AFI remains the most widely used sonographic method for assessing AFV during pregnancy (Coombe-Patterson,J.2017).

There is limited normative data for fetal bladder dimensions in the third trimester. Few studies have examined the correlation between fetal bladder size, gestational age, and AFI. Lack of

standardized ultrasound protocols for simultaneous measurement of bladder volume and AFV, inconsistent reference ranges for AFV across gestational ages, leading to variability in diagnosing oligohydramnios and polyhydramnios are some of the research gaps present in existing literature. In addition to these, conflicting evidence on the most accurate sonographic method (AFI vs. SDP) for assessing AFV and its impact on clinical outcomes and scarcity of prospective, population-specific studies linking fetal bladder measurements with perinatal outcomes are also some of the gaps in literature (Magann et al., 2007;Singh, S. et al. 2025).

Amniotic fluid (AF) is essential in determining fetal well-being for its significance in the biophysical profile. Amniotic fluid is an important contributor to the outcome of the pregnancy. Irregularities in the Amniotic Fluid Index (AFI) levels (AFI) can cause complications for the pregnant mother and fetal child. This can show the need for meticulous measurement in the AFI index for antenatal care.

This study purpose to address these gaps measuring by fetal bladder dimensions and analyzing their correlation with gestational age and AFI during the third trimester. This gap can be addressed through our prospective observational and analytical study where AFI measurements are taken in various gestational age groups and correlated with perinatal outcomes . It requires standard ultrasound procedures and access to routine obstetric patients, making it feasible within a single institution or small clinical research setup.

## CHAPTER 3

### 3.1: OBJECTIVE

To evaluate fetal bladder size and its relationship with gestational age and amniotic fluid index during the third trimester.

## CHAPTER 4

## MATERIAL AND METHODS

This study was conducted as a **cross-sectional study** at the **UOL Ultrasound Clinic, Green Town**, over a duration of **four months**. The sample included all patients who met the inclusion and exclusion criteria and visited the department during the study period, using a **convenient sampling technique**. The inclusion criteria comprised pregnant women in the **third trimester** with **singleton pregnancies, normal fetal anatomy confirmed on anomaly scan**, and **known last menstrual period (LMP) or confirmed gestational age via early ultrasound**, representing low-risk pregnancies. Exclusion criteria included cases of **oligohydramnios or polyhydramnios diagnosed before 34 weeks**, pregnancies complicated by **maternal medical conditions**, **intrauterine growth restriction (IUGR) or macrosomia**, and cases with **ruptured membranes or leaking amniotic fluid**. Ultrasound examinations were performed using a **Toshiba Aplio 300 ultrasound machine** equipped with a **3–5 MHz convex transducer**. Ethical considerations were strictly followed in accordance with the guidelines of the **University of Lahore Ethical Committee**. Written informed consent was obtained from all participants, and confidentiality of data was maintained. Participants remained anonymous throughout the study and were informed that the procedure carried no risks or disadvantages. They were also assured of their right to withdraw from the study at any stage. All collected data were securely stored, with physical records kept under lock and key and digital data protected by password.

## CHAPTER 5
## RESULTS

**Table 1**

| | N | Minimum | Maximum | Mean | Median | SD |
|---|---|---|---|---|---|---|
| Gestational Age (weeks) | 150 | 27.000 | 39.000 | 31.773 | 31.000 | 3.2772 |
| Patient Age | 150 | 18.000 | 39.000 | 26.613 | 26.000 | 5.0564 |

The table presents descriptive statistics for gestational age and patient age in a sample of 150 participants. The gestational age ranges from 27 to 39 weeks, with an average (mean) of 31.77 weeks. The median is 31 weeks. The standard deviation (SD) is 3.28 weeks, suggesting a moderate variation in gestational ages across the sample. Patient ages range from 18 to 39 years, with a mean age of 26.61 years. The median age is 26 years, very close to the mean, suggesting a roughly symmetrical age distribution. The SD is 5.06 years, indicating moderate variability in patient ages.

**Correlation**

| | |
|---|---|
| Variable Y | AFI_cm_<br>AFI (cm) |
| Variable X | Bladder_Volume_ml_<br>Bladder Volume (ml) |

| | |
|---|---|
| Sample size | 150 |
| Correlation coefficient r | -0.2735 |
| Significance level | P=0.0007 |
| 95% Confidence interval for r | -0.4156 to -0.1184 |

There is a statistically significant but weak negative correlation between fetal bladder volume and AFI in this dataset. Clinically, this may suggest that larger bladder volumes are associated with slightly lower AFI, but the strength of the relationship is limited, so other factors likely contribute more to AFI variability.

**Correlation**

| | |
|---|---|
| Variable Y | AFI_cm_<br>AFI (cm) |
| Variable X | Bladder_Width_mm_<br>Bladder Width (mm) |

| | |
|---|---|
| Sample size | 150 |
| Correlation coefficient r | -0.2919 |

| | |
|---|---|
| Significance level | P=0.0003 |
| 95% Confidence interval for r | -0.4319 to -0.1381 |

There is a statistically significant weak negative correlation between fetal bladder width and AFI. Suggesting, clinically, that larger bladder width is associated with slightly lower AFI, however it is to be noted that the relationship is weak, so other factors likely have a stronger influence on AFI.

**Correlation**

| | |
|---|---|
| Variable Y | AFI_cm_<br>AFI (cm) |
| Variable X | Bladder_Length_mm_<br>Bladder Length (mm) |

| | |
|---|---|
| Sample size | 150 |
| Correlation coefficient r | -0.2860 |
| Significance level | P=0.0004 |
| 95% Confidence interval for r | -0.4267 to -0.1318 |

There is a statistically significant weak negative correlation between fetal bladder length and AFI. While this suggests that longer fetal bladders are associated with slightly lower AFI, considering that the relationship is weak, and other factors are likely to influence AFI more strongly.

**Correlation**

| | |
|---|---|
| Variable Y | AFI_cm_<br>AFI (cm) |
| Variable X | Bladder_AP_mm_<br>Bladder AP (mm) |

| | |
|---|---|
| Sample size | 150 |
| Correlation coefficient r | -0.3093 |
| Significance level | P=0.0001 |
| 95% Confidence interval for r | -0.4474 to -0.1568 |

There is a statistically significant weak-to-moderate negative correlation between fetal bladder AP diameter and AFI. Clinically, this indicates that larger bladder AP diameters are associated with lower AFI values, although the relationship remains modest. This finding supports the trend

observed with other bladder dimensions, showing a consistent inverse relationship between bladder size and amniotic fluid volume.

**Correlation**

| | |
|---|---|
| Variable Y | Gestational_Age_weeks_ Gestational Age (weeks) |
| Variable X | Bladder_Volume_ml_ Bladder Volume (ml) |

| | |
|---|---|
| Sample size | 150 |
| Correlation coefficient r | 0.5114 |
| Significance level | P<0.0001 |
| 95% Confidence interval for r | 0.3825 to 0.6208 |

There is a statistically significant moderate positive correlation between fetal bladder volume and gestational age. Indicating that with the advancement in pregnancy, fetal bladder volume increases, reflecting physiological growth and maturation of fetal renal and urinary function.

**Correlation**

| | |
|---|---|
| Variable Y | Gestational _Age weeks_ Gestational Age (weeks) |
| Variable X | Bladder Width _mm_ Bladder Width (mm) |

| | |
|---|---|
| Sample size | 150 |
| Correlation coefficient r | 0.5026 |
| Significance level | P<0.0001 |
| 95% Confidence interval for r | 0.3723 to 0.6134 |

Fetal bladder width increases over time and with gestational age, there is a statistically significant moderate correlation. This is normal bladder development and normal growth of the fetus over time.

**Correlation**

| | |
|---|---|
| Variable Y | Gestational_ Age_weeks_ Gestational Age (weeks) |
| Variable X | Bladder _Length_ mm_ Bladder Length (mm) |

| | |
|---|---|
| Sample size | 150 |

| | |
|---|---|
| Correlation coefficient r | 0.4470 |
| Significance level | P<0.0001 |
| 95% Confidence interval for r | 0.3089 to 0.5667 |

Another statistically significant moderate correlation is the change in age of the fetus and the development of the bladder length. This change also signifies normal growth of the fetus during the third trimester. The difference in bladder width also suggested a growth change in the age of the fetus.

**Correlation**

| | |
|---|---|
| Variable Y | Gestational _Age_weeks_ Gestational Age (weeks) |
| Variable X | Bladder _AP_mm_ Bladder AP (mm) |
| Sample size | 150 |
| Correlation coefficient r | 0.4753 |
| Significance level | P<0.0001 |
| 95% Confidence interval for r | 0.3410 to 0.5906 |

This suggests growth of the bladder and advancement in gestational age. As the fetal bladder length grows and the gestational age increases, the bladder length is growing and therefore is normal growth of the bladder as pregnancy continues

.

**Analysis of covariance**

| | |
|---|---|
| Dependent | Bladder_Width_mm_ Bladder Width (mm) |
| Sample size | 150 |
| Coefficient of determination $R^2$ | 0.3357 |
| $R^2$-adjusted | 0.3078 |
| Multiple correlation coefficient | 0.5794 |
| Residual standard deviation | 7.4576 |

**Regression Equation**

| Independent variables | Coefficient | Std. Error | t | P |
|---|---|---|---|---|
| (Constant) | -15.0160 | | | |
| BPD_mm_ | 0.04246 | 0.2626 | 0.162 | 0.8718 |

| | | | | |
|---|---|---|---|---|
| Femur_Length_mm_ | -0.3870 | 0.2956 | -1.309 | 0.1926 |
| Head_Circumference_mm_ | 0.02206 | 0.005687 | 3.880 | 0.0002 |
| Gestational_Age_weeks_ | 1.5657 | 0.8432 | 1.857 | 0.0654 |
| AFI_cm_ | -0.3695 | 0.3833 | -0.964 | 0.3368 |
| Abdominal_Circumference_mm_ | 0.02270 | 0.05610 | 0.405 | 0.6864 |

**Analysis of Variance**

| Source | DF | Sum of Squares | Mean Square |
|---|---|---|---|
| Regression | 6 | 4019.3149 | 669.8858 |
| Residual | 143 | 7953.0405 | 55.6157 |
| F-ratio | | 12.0449 | |
| Significance level | | P<0.0001 | |

**Summary statistics for dependent variable and covariate(s)**

| Variable | Mean | Standard deviation |
|---|---|---|
| Bladder_Width_mm_ | 21.0272 | 8.9639 |
| BPD_mm_ | 79.5160 | 7.3815 |
| Femur_Length_mm_ | 62.0367 | 7.0049 |
| Head_Circumference_mm_ | 219.5040 | 118.6980 |
| Gestational_Age_weeks_ | 31.7733 | 3.2772 |
| AFI_cm_ | 11.4867 | 2.1292 |
| Abdominal_Circumference_mm_ | 278.7353 | 32.9529 |

**Residuals**

| | |
|---|---|
| Shapiro-Wilk test for Normal distribution | W=0.9845 accept Normality (P=0.0898) |

The model for fetal bladder width is statistically significant ($P < 0.0001$), and accounts for about a third of the total variability in bladder width. The only variable that was statistically significant was head circumference, and it was also found that larger head circumference means larger bladder width as well. As in the growth of the fetus, head circumference also showed a positive relation in growth, but also did not reach any statistical significance of 0.05. Other factors that were evaluated did not independently contribute significantly to the bladder width, factors such as BPD, femur length, AFI, and abdominal circumference.The model residuals were normally distributed, indicating a good model fit.

Analysis of Covariance

| | |
|---|---|
| Dependent | Bladder_Length_mm_ Bladder Length (mm) |
| Sample size | 150 |
| Coefficient of determination $R^2$ | 0.2668 |
| $R^2$-adjusted | 0.2361 |
| Multiple correlation coefficient | 0.5166 |
| Residual standard deviation | 9.8576 |

**Regression Equation**

| Independent variables | Coefficient | Std. Error | t | P |
|---|---|---|---|---|
| (Constant) | -8.8286 | | | |
| BPD_mm_ | 0.1881 | 0.3472 | 0.542 | 0.5887 |
| Femur_Length_mm_ | -0.2599 | 0.3908 | -0.665 | 0.5070 |
| Head_Circumference_mm_ | 0.02630 | 0.007517 | 3.498 | 0.0006 |
| Gestational_Age_weeks_ | 0.9462 | 1.1145 | 0.849 | 0.3973 |
| AFI_cm_ | -0.6857 | 0.5067 | -1.353 | 0.1781 |
| Abdominal_Circumference_mm_ | 0.02942 | 0.07416 | 0.397 | 0.6922 |

**Analysis of Variance**

| Source | DF | Sum of Squares | Mean Square |
|---|---|---|---|
| Regression | 6 | 5057.2107 | 842.8685 |
| Residual | 143 | 13895.5037 | 97.1714 |
| F-ratio | | 8.6740 | |
| Significance level | | P<0.0001 | |

**Summary statistics for dependent variable and covariate(s)**

| Variable | Mean | Standard deviation |
|---|---|---|
| Bladder_Length_mm_ | 26.1637 | 11.2783 |
| BPD_mm_ | 79.5160 | 7.3815 |
| Femur_Length_mm_ | 62.0367 | 7.0049 |
| Head_Circumference_mm_ | 219.5040 | 118.6980 |

| | | |
|---|---|---|
| Gestational_Age_weeks_ | 31.7733 | 3.2772 |
| AFI_cm_ | 11.4867 | 2.1292 |
| Abdominal_Circumference_mm_ | 278.7353 | 32.9529 |

**Residuals**

| | |
|---|---|
| Shapiro-Wilk test for Normal distribution | W=0.8080 reject Normality (P<0.0001) |

The overall ANCOVA model is statistically significant (P < 0.0001), explaining about one quarter of the variability in fetal bladder length. Among all predictors, head circumference is the only significant independent predictor of bladder length. Fetuses with larger head circumferences tend to have longer bladders. Other factors like BPD, femur length, gestational age, AFI, and abdominal circumference, were not found to have any significant independent effects on AP diameter of the bladder. The residuals adhered to a normal distribution, which validated the model assumptions were satisfied, and the findings are conclusive. In conclusion, these findings suggest that fetal size (especially HC) holds significant influence in determining bladder AP dimension, while other biometric and fluid parameters are of limited influence.

**Analysis of Covariance**

| | | |
|---|---|---|
| Dependent | | Bladder_AP_mm_ Bladder AP (mm) |
| Sample size | 150 | |
| Coefficient of determination $R^2$ | | 0.3019 |
| $R^2$-adjusted | | 0.2726 |
| Multiple correlation coefficient | | 0.5495 |
| Residual standard deviation | | 7.7598 |

**Regression Equation**

| Independent variables | Coefficient | Std. Error | t | P |
|---|---|---|---|---|
| (Constant) | -1.4023 | | | |
| BPD_mm_ | -0.2404 | 0.2733 | -0.880 | 0.3804 |
| Femur_Length_mm_ | -0.1462 | 0.3076 | -0.475 | 0.6354 |
| Head_Circumference_mm_ | 0.02161 | 0.005918 | 3.651 | 0.0004 |
| Gestational_Age_weeks_ | 1.3251 | 0.8774 | 1.510 | 0.1332 |
| AFI_cm_ | -0.5658 | 0.3989 | -1.418 | 0.1582 |
| Abdominal_Circumference_mm_ | 0.04666 | 0.05838 | 0.799 | 0.4255 |

**Analysis of Variance**

| Source | DF | Sum of Squares | Mean Square |
|---|---|---|---|
| Regression | 6 | 3724.3876 | 620.7313 |
| Residual | 143 | 8610.6852 | 60.2146 |
| F-ratio | 10.3087 | | |
| Significance level | P<0.0001 | | |

**Summary statistics for dependent variable and covariate(s)**

| Variable | Mean | Standard deviation |
|---|---|---|
| Bladder_AP_mm_ | 23.7628 | 9.0987 |
| BPD_mm_ | 79.5160 | 7.3815 |
| Femur_Length_mm_ | 62.0367 | 7.0049 |
| Head_Circumference_mm_ | 219.5040 | 118.6980 |
| Gestational_Age_weeks_ | 31.7733 | 3.2772 |
| AFI_cm_ | 11.4867 | 2.1292 |
| Abdominal_Circumference_mm_ | 278.7353 | 32.9529 |

**Residuals**

| | |
|---|---|
| Shapiro-Wilk test for Normal distribution | W=0.9826 accept Normality (P=0.0554) |

The ANCOVA model for fetal bladder AP diameter is statistically significant overall ($P < 0.0001$), explaining about 30% of the variability in AP diameter. Among the independent variables, head circumference is the only significant positive predictor, suggesting that fetuses with larger head circumferences tend to have greater bladder AP diameters This result is similar to the trend of head circumference being the only significant predictor for rest of bladder dimensions. Other variables, including BPD, femur length, gestational age, AFI, and abdominal circumference, showed no significant independent effects on bladder AP diameter. The residuals followed a normal distribution, confirming that model assumptions were satisfied and the results are robust. Overall, the findings indicate that fetal size (particularly head circumference) plays a meaningful role in determining bladder AP dimension, while other biometric and fluid parameters contribute minimally.

**Analysis of Covariance**

| | |
|---|---|
| Dependent | Bladder_Volume_ml_ Bladder Volume (ml) |
| Sample size | 150 |

| | |
|---|---|
| Coefficient of determination $R^2$ | 0.3122 |
| $R^2$-adjusted | 0.2834 |
| Multiple correlation coefficient | 0.5588 |
| Residual standard deviation | 9.2169 |

**Regression Equation**

| Independent variables | Coefficient | Std. Error | t | P |
|---|---|---|---|---|
| (Constant) | -39.5494 | | | |
| BPD_mm_ | -0.4365 | 0.3246 | -1.345 | 0.1809 |
| Femur_Length_mm_ | 0.03158 | 0.3654 | 0.0864 | 0.9312 |
| Head_Circumference_mm_ | 0.01539 | 0.007029 | 2.190 | 0.0302 |
| Gestational_Age_weeks_ | 3.1113 | 1.0421 | 2.986 | 0.0033 |
| AFI_cm_ | -0.03394 | 0.4738 | -0.0716 | 0.9430 |
| Abdominal_Circumference_mm_ | -0.07026 | 0.06934 | -1.013 | 0.3127 |

**Analysis of Variance**

| Source | DF | Sum of Squares | Mean Square |
|---|---|---|---|
| Regression | 6 | 5515.2833 | 919.2139 |
| Residual | 143 | 12148.0739 | 84.9516 |

| | |
|---|---|
| F-ratio | 10.8204 |
| Significance level | P<0.0001 |

**Summary statistics for dependent variable and covariate(s)**

| Variable | Mean | Standard deviation |
|---|---|---|
| Bladder_Volume_ml_ | 9.9654 | 10.8879 |
| BPD_mm_ | 79.5160 | 7.3815 |
| Femur_Length_mm_ | 62.0367 | 7.0049 |
| Head_Circumference_mm_ | 219.5040 | 118.6980 |
| Gestational_Age_weeks_ | 31.7733 | 3.2772 |
| AFI_cm_ | 11.4867 | 2.1292 |
| Abdominal_Circumference_mm_ | 278.7353 | 32.9529 |

**Residuals**

| | |
|---|---|
| Shapiro-Wilk test for Normal distribution | W=0.7843 reject Normality (P<0.0001) |

The model is significant overall accounting for ~31% of bladder volume variation. Gestational age is the strongest and head circumference is a weaker significant predictor. On the other hand, BPD, femur length, AFI, and abdominal circumference were non-significant predictors. The results show that bladder volume increases with gestational age and to a lesser degree with head circumference.

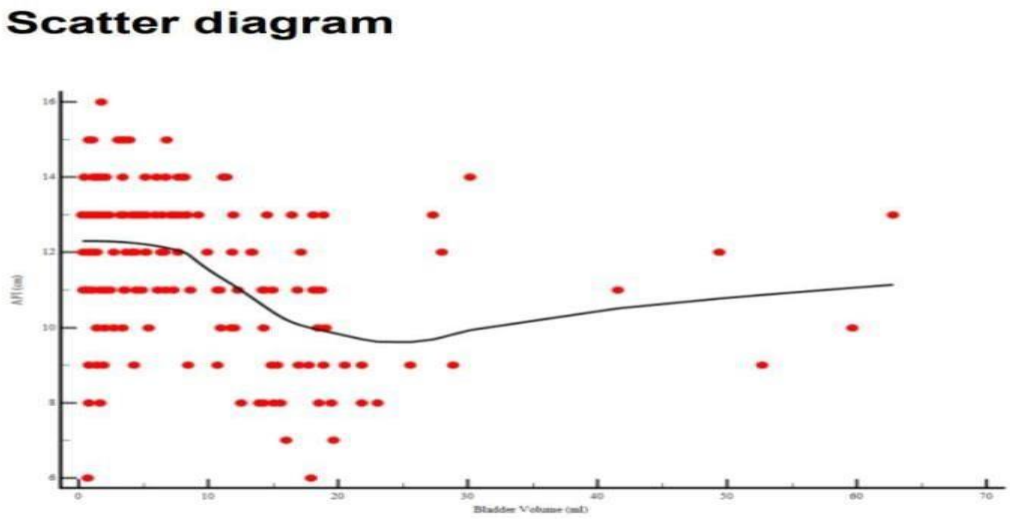



**Fig 1:The scatterplot represents fetal bladder volume (ml) versus amniotic fluid index (AFI) and individual data points are colored in red. It appears that there is a slight decline in AFI with increasing bladder volume up to the midrange and then a gradual increase towards the end.**

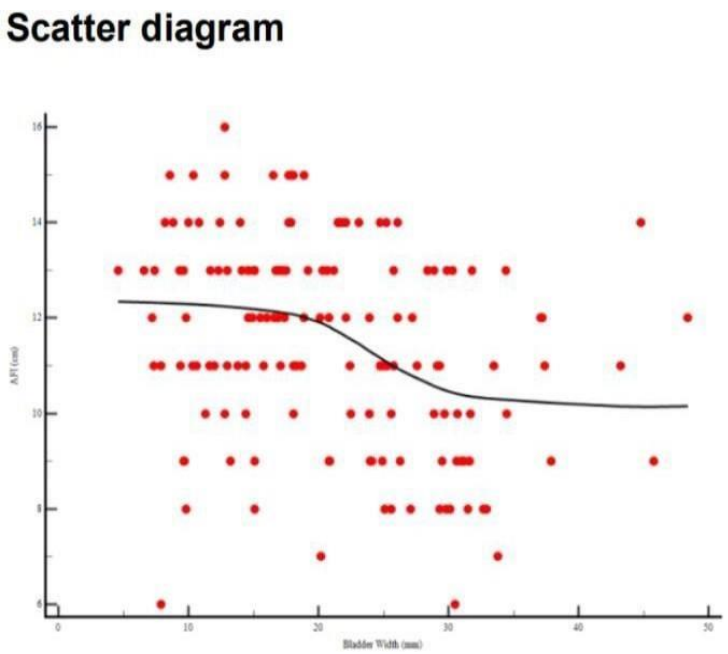



**Fig 2 :The scatter plot shows the distributions of Amniotic fluid index values at various fetal bladder widths and with the red data points. The smooth trend line indicates that there is a small decrease in AFI with increasing bladder width.**

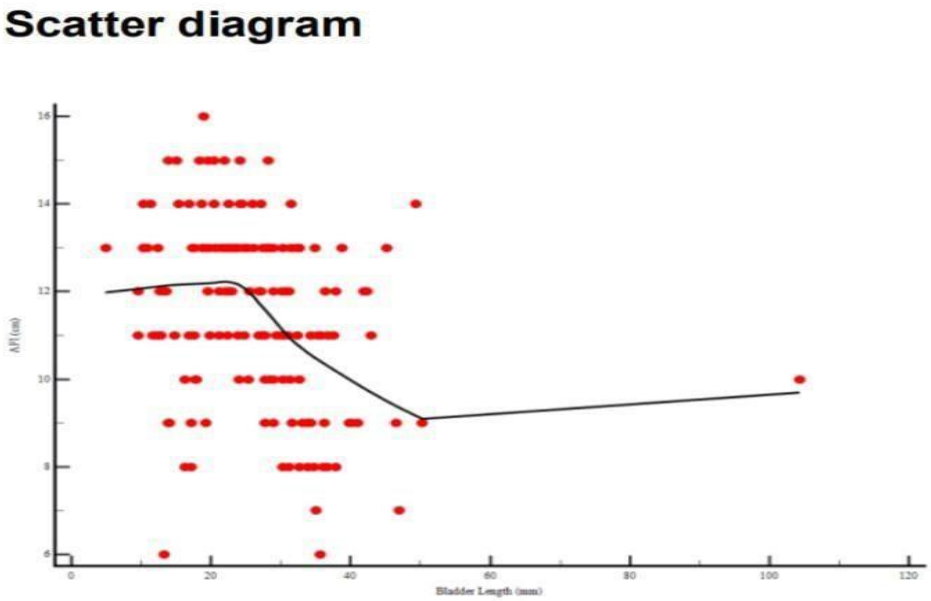



**Fig 3:The scatter plot bladder length and AFI shows a wide dispersion of values with no strong linear correlation. The trend line in the middle length range is decreasing quickly and then has a sharp increase at the higher bladder lengths.**

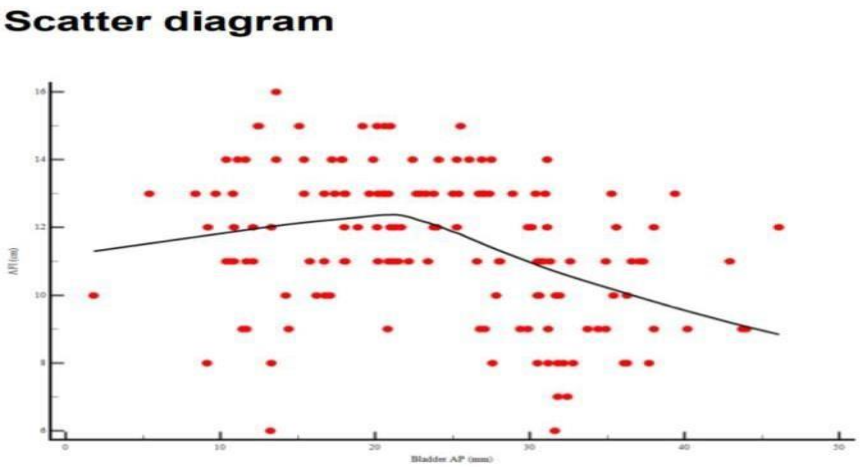



**Fig 4: The scatter plot of the Amniotic Fluid Index values versus the AP Diameter of the Fetal Bladder in the red box. The line of best fit shows a gentle increase in AFI followed by a slight decline as the AP diameter of the bladder increases.**

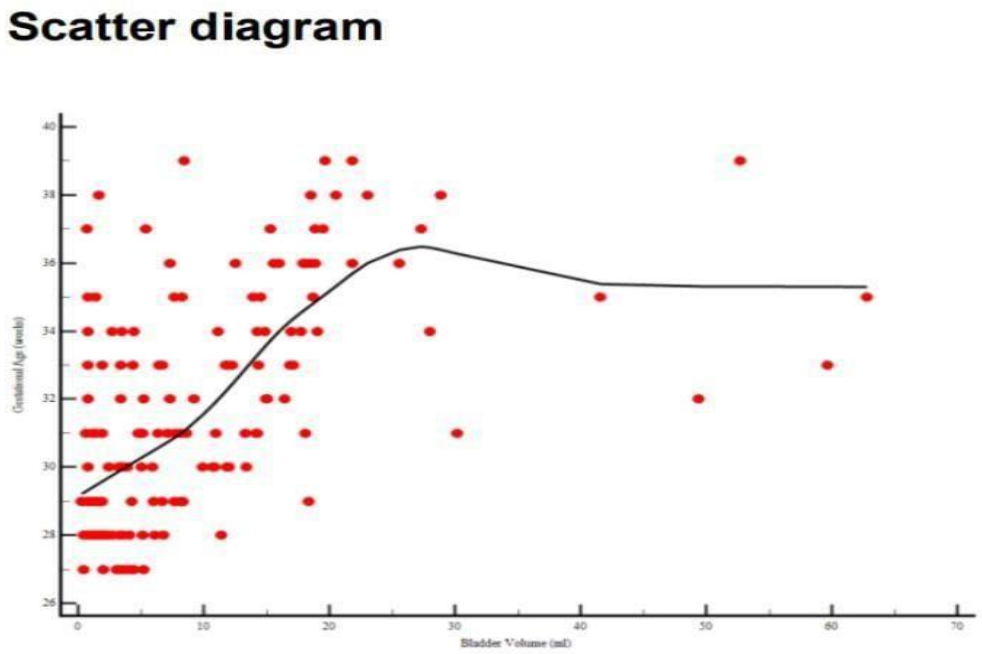



**Fig 5 : shows a scatter plot of the volume of the bladder versus the age of the fetus. The result shows that there isn't a strong linear relationship as there are clusters around the lower volume. The line of best fit indicates a slight increase in lower volume bladders that levels off around 25 to 30 ml**

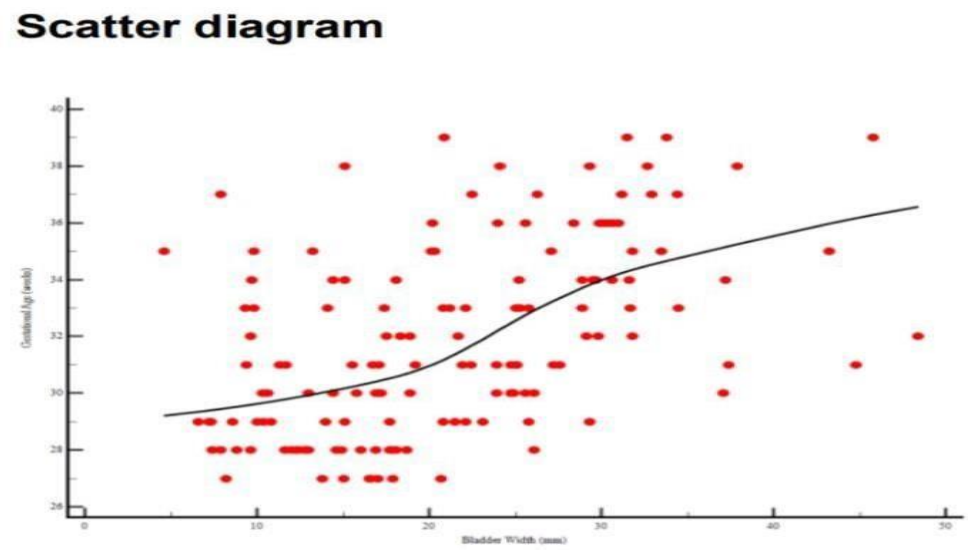
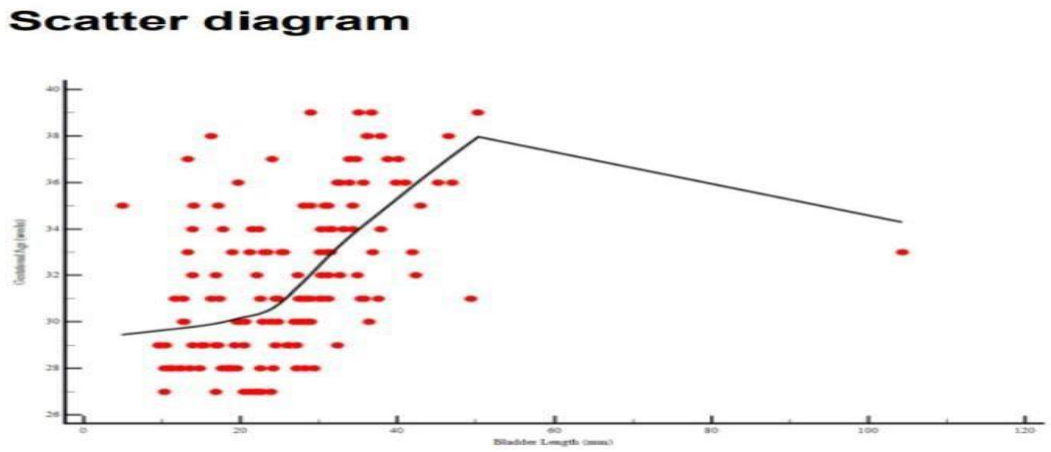



**Fig 6 :A positive correlation between bladder width and gestational age is illustrated in the scatter plot beginning and finishing on the edges of the range on the horizontal and vertical axes respectively, the trend line indicates that bladder width widens with more advanced gestational ages**




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**Fig 7 : From the fitted line of the scatter plot, there is a positive correlation between bladder length and gestational age, with a decrease in slope and a subsequent increase of bladder length as time goes on, causing most of the data in the short bladder length region.**

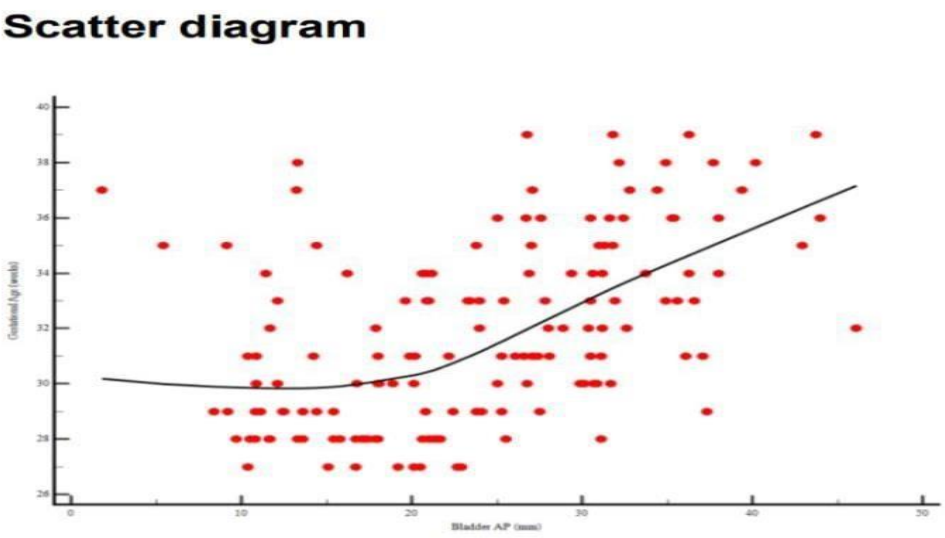



**Fig 8: In the scatter plot having the relationship between AFI(cm) and the bladder width AP diameter (mm) most data points have little variation from the trend line. The relationship is closely formed and contrasts from the distance the points have from the line. A slight increase in AFI is shown in the mid section of the bladder width AP range .**

## CHAPTER 6
## DISCUSSION

The present study evaluated the relationship between fetal bladder dimensions, gestational age, and amniotic fluid index during the third trimester of pregnancy. The findings provide important insight into fetal urinary system growth and its contribution to amniotic fluid dynamics, while also emphasizing that these parameters are regulated independently in late gestation. All fetal bladder dimensions, including bladder volume, width, length, and anteroposterior diameter, demonstrated a significant positive correlation with gestational age. Among these parameters, bladder volume showed the strongest association, indicating progressive enlargement of the fetal bladder as pregnancy advances. This pattern reflects normal maturation of the fetal renal and urinary systems during the third trimester. These findings are consistent with previous studies that have documented a steady increase in fetal bladder size with advancing gestation. The fetal urine production and bladder capacity increase progressively in late pregnancy, corresponding with renal maturation and overall fetal growth.

The stronger association between gestational age and bladder volume compared with linear bladder measurements in the present study suggests that bladder growth in late pregnancy may occur predominantly through volumetric expansion rather than uniform linear enlargement. This observation is in agreement with prior ultrasound-based studies that identified bladder volume as a more sensitive indicator of urinary system development than individual linear dimensions. In contrast, the present study did not demonstrate a strong positive relationship between fetal bladder dimensions and amniotic fluid index. Instead, weak negative correlations were observed between AFI and bladder volume as well as other bladder parameters.Studies evaluating hourly fetal urine production have shown that variations in urine output do not consistently result in corresponding changes in AFI, supporting the concept that amniotic fluid volume is not solely dependent on fetal urine production.

Previous research has established that amniotic fluid regulation is a multifactorial process involving fetal swallowing, intramembranous absorption, placental water transfer, and trans membranous flow in addition to fetal urine production. The findings of the present study further

support this multifactorial model of amniotic fluid regulation. The weak inverse association observed between AFI and bladder dimensions may reflect normal physiological changes toward term, as AFI is known to gradually decline in late pregnancy despite continued fetal growth and increasing urine production. Similar physiological declines in AFI after 32 to 34 weeks of gestation have been reported in earlier studies.

The use of AFI in the present study allowed comprehensive assessment of amniotic fluid volume across all four uterine quadrants. Previous studies employing the single deepest vertical pocket method have reported inconsistent correlations between fetal urinary output and amniotic fluid volume. AFI has been shown to be more sensitive in detecting subtle changes in amniotic fluid and to offer better reproducibility in research settings. Therefore, the absence of a strong correlation between fetal bladder dimensions and AFI in this study is unlikely to be attributable to methodological limitations and more likely reflects true physiological independence between these parameters in late gestation. Further analysis demonstrated that head circumference was the most consistent independent predictor of fetal bladder dimensions, while gestational age independently predicted bladder volume. Similar observations have been reported in previous studies, including work by Goldstein et al., who demonstrated that fetal organ growth, including urinary tract structures, correlates more strongly with global growth indicators such as head circumference than with amniotic fluid measurements. The present study reinforces the concept that bladder development is part of generalized fetal growth rather than a direct determinant of amniotic fluid volume.

Clinically, the findings of this study suggest that fetal bladder measurements may serve as supportive indicators of fetal maturity and growth during the third trimester. However, the lack of a meaningful association between bladder dimensions and AFI indicates that bladder measurements should not be used in isolation to assess amniotic fluid adequacy in low-risk pregnancies. Instead, fetal bladder findings should be interpreted alongside comprehensive biometric and amniotic fluid assessments, particularly when evaluating suspected urinary tract abnormalities or disorders of amniotic fluid volume.

## CHAPTER 7
## CONCLUSION

This reserch shows that there is a significant increase in fetal bladder volumes with the increase in average gestational age during the third trimester representing a typical range of maturation and excretory urinary functioning of kidneys. However, in this study, volume of amniotic fluid and fetal bladder increased, with no significant correlation suggesting that volume of fetal bladder and amniotic fluid index (AFI) may be controlled separately.

### RECOMMENDATION

- Future research should involve large, multi-centre studies to strengthen the validity of the findings.
- It would help to run longitudinal projects that follow fetal bladder growth through each stage of pregnancy, noting subtle changes like the gradual stretch of the tissue over time.
- Efforts should be made to standardize ultrasound measurement techniques and reduce inter-observer variation.
- Further work may explore the relationship between bladder dimensions, amniotic fluid, and Perinatal outcomes, and compare different ultrasound technologies for accuracy.
- AI-based measurement tools and additional fetal or maternal parameters could also improve the understanding of fetal urinary and amniotic fluid dynamics.

**7.3: LIMITATION**

- Since this study was only conducted in one center, the results may not be relevant to other centers or populations.
- The sample size, which was sufficient to perform the correlation analysis, may not be large enough to demonstrate the heterogeneity in fetal bladder dimensions and AFI, for all the periods of gestation or for all the demographic strata.
- This study was cross-sectional in design and therefore only able to describe the association of bladder volume, AFI, and gestational age. There is no way to measure the longitudinal trends and the cause-and-effect relationship.
- Some maternal factors (hydration state, body mass index, time since last void, etc.) which could influence the volume of amniotic fluid, were not controlled and could therefore influence the AFI.

**CHAPTER 8**

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