Fetal Surveillance in Diabetic Pregnancies

Terence Tzu-Hsi Lao, MBBS(HK), MRCOG, FRCOG, FHKCOG, FHKAM(O&G), MD

The perinatal outcome in pregnancies complicated by maternal diabetes mellitus (DM) has seen significant improvement over the past decades. One of the major contributions is the increased understanding and application of fetal surveillance methods to assess and monitor fetal well being. It has been shown more than 2 decades ago that the benefits of fetal assessment include not only the identification of the compromised fetus for timely intervention, but also the avoidance of unnecessary intervention, especially before term, in fetuses who are not compromised.[1] In most centres, routine fetal monitoring and assessment in the last trimester has now become part of the standard protocol in the management of diabetic pregnancies, especially in those with insulin-dependent DM (IDDM).

Currently, the great majority of diabetic pregnancies are due to gestational DM (GDM) that can be treated satisfactorily with diet control. As GDM is generally milder than pre-existing or pre-gestational DM (PGDM), the importance of fetal surveillance in pregnancies complicated by GDM is often overlooked. Nevertheless, large-scale studies have indicated an increased perinatal mortality associated with GDM.[2,3] When the World Health Organization criteria[4] is applied to Asian populations, more than 95% of the cases of GDM belong to the milder category of impaired glucose tolerance.[5,6] Yet GDM remains to be one of the important causes of stillbirth.[7] Indeed, the rate of fetal loss and perinatal mortality in GDM was even higher than that of PGDM.[2] These observations suggest that pregnancies complicated by GDM should receive a similar degree of attention to those involving PGDM so far as fetal risk is concerned, and regular fetal surveillance should be applied to all diabetic pregnancies irrespective of the mode of treatment.

In principle, fetal assessment in diabetic pregnancies should include three aspects, as shown in Table 1. For the majority of women who have received antenatal care before 20 weeks gestation, routine ultrasound scanning to exclude fetal anomalies is usually performed by the time GDM is diagnosed, and repeat detailed scanning for fetal anomalies is unnecessary. However, in women with GDM diagnosed in the first half of pregnancy, and in women with PGDM, thorough ultrasound assessment for fetal anomalies, including one at 22 weeks gestation to exclude fetal cardiac abnormalities, should be arranged. It goes without saying that monitoring of fetal growth and assessing fetal size is important in all diabetic pregnancies. These two aspects have been covered in numerous publications in the literature and therefore will not be addressed further in this review, which will focus on the surveillance of fetal well-being in diabetic pregnancies.

METHODS OF FETAL SURVEILLANCE

There are a number of established methods of fetal surveillance, which

Table 1. Fetal Assessment in Diabetic Pregnancies

Detection of fetal anomalies - Allows counselling for termination versus continuation of pregnancy - Helps planning for the time and mode of delivery, and arrangement with neonatologists to standby, in case of significant fetal anomalies
Monitoring fetal growth and estimating fetal size - Allows early detection of diabetes effect on the fetus - Helps identify the unexpectedly small fetus for close monitoring - Helps identify the fetus with accelerated growth, to allow planning for time and mode of delivery - Helps to guide diabetic treatment
Surveillance of fetal well-being - Allows early detection of fetal compromise - Allows planning for the time and mode of delivery - Avoids unnecessary intervention and associated problems, such as prematurity in healthy fetuses

can be applied in various combinations to diabetic pregnancies. The existence of different protocols in different centres is the evidence that there should not be any hard and fast rule. Since the clinical circumstances may vary from woman to woman, and one has to also consider the resource implications and logistical issues, the important thing to understand is that fetal surveillance should be flexible and applied with common sense. It may be necessary to choose the method that can provide the most useful information at the time for the particular individual, within the framework of each protocol.

The simplest and most easily applied method of fetal surveillance is the fetal kick count. In China, many couples are issued a measuring tape, a fetal stethoscope, and a fetal kick chart for the husbands to monitor fetal growth and well-being at home. The fetal kick count can be used as the first line of fetal monitoring for the majority of diabetic pregnancies. In pregnancies with additional risk factors or other complications, more intensive surveillance with one or more of the following methods can be applied. (Table 2)

Cardiotocography

Cardiotocography (CTG) is an objective and reproducible test that can be applied in the form of a nonstress test (NST) or a contraction stress test (CST). However, the latter is seldom performed because of the increased complexity and time involved, and a potential risk to the high-risk fetus due to uterine stimulation.

While the NST is relatively easy to perform and is a popular method of fetal surveillance, the fetal heart rate pattern may be influenced by maternal glycaemic level and prandial status. Teramo et al[8] studied 145 patients with IDDM using NST from 32 weeks onwards. They found suspicious and pathological patterns in 6.2% and 12.4% of the patients, respectively. A suspicious or pathological NST was found in 35% of those with poor diabetic control (defined as a mean HbA_{1c} of ≥8.0% in the last trimester and/or mean fasting blood glucose or mean blood glucose of the 24 hour profile above 7.0 mmol/L during the past 2 weeks before delivery) compared with 15% of patients with good glycaemic control ($p<0.02$). Furthermore, the mean HbA_{1c} in patients with pathological NST was significantly higher than that of patients with normal NST (7.63 ± 0.87% vs 6.91 ± 0.83%, $p<0.02$). On the other hand, there was no significant difference in the mean fasting glucose or mean glucose of the 24-hour profile between patients with pathological or normal NST. When perinatal outcomes were examined, the group with pathological NST had significantly shorter gestational age, lower mean birthweight and higher incidence of respiratory distress, as well as a trend towards higher incidence of low Apgar score and perinatal death.

Table 2. Commonly Used Methods of Assessing Fetal Well Being

Subjective method
- Fetal kick count by the mother
Objective methods
- Cardiotocography (CTG)
- Nonstress test (NST)
- Contraction stress test (CST)
- Biophysical profile score (BPS) - with or without NST
- Amniotic fluid index (AFI)
- Umbilical artery Doppler flow velocity waveforms

In the most recent report by Serra-Serra et al,[9] 21 PGDM and 23 GDM patients were compared with 18 controls. The CTG was performed before and 1 hour after meal, and the analysis was done with a computerized system looking at changes in basal fetal heart rate, accelerations and variations. While the pre-meal and post-meal glucose levels varied from 2.7 to 10.5 mmol/L and 4.2 to 14.8 mmol/L, respectively, no significant changes in the CTG parameters were noted. There was no demonstrable correlation between glycaemia and fetal heart rate changes, and no correlation between insulin versus diet treatment.

The findings of these studies suggested that, for practical purpose, neither maternal glycaemia nor the prandial state during pregnancy have any significant effect on fetal heart rate or its patterns. Poor control of diabetes is likely to be associated with higher incidence of abnormal fetal heart rate patterns not because of poor glycaemic control *per se*, but because of fetal distress and placental insufficiency secondary to poor glycaemic control. Thus the NST should not be used to assess diabetic control, but it can be a reliable method to identify the compromised fetus, irrespective of glycaemic control in the antepartum period. Nevertheless, there have been anecdotes of an association between fetal bradycardia and maternal symptomatic hypoglycaemia during labour.[10] An increase in frequency and amplitude of fetal heart rate accelerations has also been recorded following a 150-minute hyperinsulinaemic hypoglycaemic clamp with maintenance of maternal arterial blood glucose concentration at approximately 2.2 mmol/L in the third trimester in IDDM patients.[11] Although no apparent harmful effects on the fetus were observed in these reports, it is worthwhile measuring maternal blood glucose concentration irrespective of maternal symptoms, and treating hypoglycaemia if present, when there are unexplained and persistent changes in the baseline heart rate or the frequency and amplitude of accelerations, in the antepartum or intrapartum period in diabetic patients.

Fetal Biophysical Profile

It is a common maternal experience that fetal movements increase following a meal, and many have deduced that the physiological increase in maternal blood glucose after a meal is a stimulus for fetal activity. Indeed, fetal breathing movements (FBM) increase postprandially and after administration of oral glucose to normoglycaemic mothers.[12] Fur-thermore, it was found some years ago that while the percentage incidences of FBM, fetal trunk movement (FTM) and total fetal activity (TFA) are constant between 31 to 40 weeks,[13] those of FBM and TFA were directly related to the level of blood glucose, and abnormal patterns of FBM had been found in diabetic pregnancies.[14] Thus, maternal prandial status and glycaemia could exert an influence on the fetal biophysical profile.

When 30 minutes real-time ultrasound recordings were performed serially in a mixed group

(n=25) of PGDM and GDM pregnancies, most of which required insulin, no difference in percentage incidences of FBM and TFA between PGDM and GDM pregnancies could be found.[13] However, the percentage incidences of FBM and TFA were significantly higher in both groups compared with those in normal controls. Pregnancies with fetal problems, including several fetuses not identified by CTG, showed decreased FBM, FTM and TFA, as in nondiabetic pregnancies with hypoxic fetuses, despite similar glycaemic control to the subgroup of diabetic pregnancies without complications and delivering appropriate-for-gestational age (AGA) infants.

Subsequent studies also confirmed that neither short- or long-term maternal glycaemic levels correlated well with fetal biophysical performance,[15] and that there was no association between gross fetal body movements with fetal plasma glucose concentrations even though severe maternal hyperglycaemia can be associated with fetal tachypnoea.[12] The fetal biophysical profile can be used to generate the biophysical profile score (BPS), using FBM, body movements, tone and the largest amniotic fluid pocket, with or without the NST, which can be done alternatively with the BPS, as the parameters for assessment. A score of less than six out of eight (when NST is not performed) in diabetic pregnancies is a cause for concern and the fetus should be considered as compromised. In the study of Johnson et al,[16] complete BPS, including NST, was performed serially in 238 well-controlled diabetic pregnancies, including 188 pregnancies complicated by GDM. The overall incidence of abnormal score (persistent score of 6/10 or ≤4/10) was 3.3%, and the corrected perinatal mortality was zero. Pregnancies with abnormal scores had mandatory intervention with a caesarean section rate of 50%. Neonatal intensive care unit (NICU) admission was 37.5% (3/8) compared with 10% in patients with a normal BPS.

The results of these studies indicate that, although maternal hyperglycaemia may influence the percentage incidence of certain parameters, there is no need to adjust for any prandial effect when assessing fetal well being, and that abnormal findings reflect fetal compromise rather than maternal glycaemic status.

Fetal Umbilical Artery Doppler Velocimetry

The reports of the effect of maternal diabetes on fetal umbilical artery Doppler flow velocity waveforms are conflicting. In insulin-dependent diabetic pregnancies, it has been shown that the umbilical artery systolic/diastolic (S/D) ratio decreases with advancing gestation as in normal pregnancies, and there was no correlation between the mean third trimester S/D ratio and either the HbA_{1c} or mean glucose concentration.[17] This report was supported by later studies,[18,19] which have found that fetal placental circulation was not influenced by short- or long-term glucose regulation, and fetal metabolic acidosis exists without changes in fetal placental circulation.[20]

On the other hand, a significant positive correlation between S/D ratio in the third trimester and maternal serum glucose concentration,[21] and a significant difference in the third trimester umbilical artery Doppler S/D ratio between well controlled and poorly controlled diabetic patients,[22] have been reported. Similarly, an increase in maternal plasma glucose has been demonstrated to result in increased umbilical artery pulsatility index (PI) and decreased umbilical artery blood flow.[23] The relationship between maternal hyperglycaemia and increased placental vascular resistance has been attributed to functional changes consequent to an increase in the thromboxane A2 to prostacyclin ratio.[24-26] In this scenario, the circadian fluctuations of blood glucose could result in fetal ketoacidosis, which in turn leads to vasoconstriction of placental vasculature, that affects fetal haemodynamics.[25] This hypothesis is

supported by the observation that in IDDM pregnancies, no significant difference in placental weight or morphology could be found between those with abnormal versus normal Doppler velocimetry.[27] The investigators concluded that the cause of the abnormal Doppler results is a functional rather than structural placental process, and that there is an association between glycaemic control and Doppler results. Nevertheless, the mean second and third trimester S/D ratio was also significantly higher in patients with vascular disease.[17] Abnormal third trimester S/D ratio was also associated with pre-eclampsia and AGA fetus in patients without vascular disease, and fetal growth restriction in patients with vascular disease.[17] Thus irrespective of the underlying mechanism, an abnormal umbilical artery Doppler result in diabetic pregnancies is suggestive of an abnormal placental process.

It has since been shown that increased S/D ratio in the third trimester was associated with increased stillbirths and neonatal morbidity.[21] IDDM pregnancies with abnormal Doppler velocimetry were three times more likely to have poor glycaemic control, and there were more infants who were delivered earlier with lower birthweight, delivered by caesarean section because of fetal distress, and had hyperbilirubinaemia and NICU stay for 2 or more days.[27] This also suggests that umbilical artery Doppler studies are more helpful in identifying small-for-gestational age, but not large-for-gestational age, infants who are at risk of adverse outcomes. In the most recent report on 67 patients with IDDM, abnormal PI (>95th percentile) could be found in 34% of the patients.[28] An abnormal PI was associated with increased maternal blood glucose and/or HbA_{1c}, and increased neonatal morbidity that included respiratory distress syndrome (13% vs 4.5%, $p<0.005$), hyperbilirubinaemia (35% vs 4.5%, $p<0.001$), hypoglycaemia (35% vs 7%, $p<0.001$) and admission to NICU (30% vs 7%, $p<0.001$). These differences were found despite the absence of any difference in birthweight or gestational age.

In GDM pregnancies, an abnormal PI (>2 standard deviation above mean for gestational age) was found in 13% of 89 patients.[29] There was no difference in the incidence between diet treated (13%) or insulin treated (14%) patients, and there was no difference in the maternal mean glucose or HbA_{1c} at the time of testing. The group with abnormal PI had increased incidence of caesarean section for fetal distress (42% vs 16%, $p<0.001$), neonatal hyperbilirubinaemia (25% vs 10%, $p<0.001$) and hypoglycaemia (25% vs 5%, $p<0.001$). While the birthweight appeared to be lower in the group with abnormal PI, there was no difference once correction was made for gestational age (36 ± 1.2 weeks vs 38 ± 1.9 weeks).

The findings in both IDDM and GDM pregnancies therefore indicate that while maternal glycaemia might influence umbilical artery Doppler velocimetry, abnormal Doppler findings should be interpreted as a reflection of abnormal placental function and fetal compromise in the same way as in other complicated pregnancies, and appropriate action should be taken accordingly.

APPLICATION OF FETAL SURVEILLANCE IN DIABETIC PREGNANCIES

The objectives of fetal surveillance in GDM are the early identification of antepartum fetal distress, the prediction of intrapartum fetal distress and the prevention of intrauterine death. It is advocated that fetal surveillance should commence in the third trimester, and its frequency should depend on glycaemic control and the presence or absense of other complications.[30]

In one study, 114 patients with IDDM were monitored from week 28 to week 30 with the NST, which was followed by the BPS if the NST was nonreactive.[31] The BPS was required after 8.0% of NSTs, and 8.8% of the patients

were delivered because of abnormal fetal condition, which tended to be associated with vascular disease, nephropathy and hypertension, but not with differences in the glycaemic parameters. In another study of 2,134 diabetic pregnancies that included 1,390 Class A patients, monitoring was performed with twice-weekly NST and amniotic fluid evaluation, and caesarean section for fetal distress was used as the outcome variable.[32] There were five stillbirths. All stillbirths were in Class A_2, and recognized death occurred >4 days after the last test. These five cases included two with major congenital anomalies (omphalocoele and encephalocoele), one died during delivery from severe shoulder dystocia, and two at 36 and 38 weeks without any apparent cause. The corrected stillbirth rate was 1.4/1000. Of note, the factors most predictive of caesarean section for fetal distress were deceleration (OR 3.60, 95% CI 2.14-6.06), nonreactive NST (OR 2.68, 95% CI 1.60-4.49) and the interaction of both a nonreactive NST and decelerations (OR 5.63, 95% CI 2.67-11.9). Amniotic fluid assessment by the largest vertical pocket or amniotic fluid index was, however, not predictive.

When NST, BPS and umbilical artery Doppler velocimetry were compared for the prediction of adverse outcome in 207 diabetic pregnancies, the relative risk for adverse outcome for these three tests were 1.7 (95% CI 1.2-2.5), 1.7 (95% CI 0.9-2.9) and 2.6 (95% CI 1.9-3.5), respectively.[33] The prevalence of adverse outcomes increased from 57.9% with one abnormal test result, to 71.4% with two abnormal test results, and to 100% with all three test results being abnormal. The combination of abnormal Doppler velocimetry and nonreactive NST was associated with 100% adverse outcome, while the combination of nonreactive NST and abnormal BPS (≤6) was associated with only 43% adverse outcome. Of note, 24% of the infants of Class A patients had an adverse outcome, and 64% of the adverse outcomes occurred in Class A and B pregnancies, suggesting that fetal surveillance had been under-utilized in this group of patients.

The literature suggests that either NST or BPS could be the first-line objective test to be applied regularly. If the NST alone is used, it should be backed-up by BPS. In the majority of cases, NST or BPS alone is sufficient. However, in special circumstances, such as multifetal pregnancies, excessive or restricted fetal growth, or significant complications (pre-eclampsia and antepartum haemorrhage), umbilical artery Doppler studies should be performed in addition. In practice, maternal involvement in the surveillance by means of fetal activity counts should be encouraged in all patients. Although there is no data in the literature comparing the use of the fetal kick count with other means of fetal surveillance in diabetic pregnancies, this allows daily monitoring of fetal well-being while objective tests for outpatients can only be done at intervals. Furthermore, one also has to balance between over-monitoring and its associated problems, such as resource utilization and logistics and the effect on the mother and her family, with the risk of missing a compromised fetus. Therefore the monitoring of each pregnancy needs to be individualized, taking into account the maternal education level, occupations of the couple and family situation, in addition to the medical aspects listed in Table 3.

CONCLUSION

The combination of subjective assessment by fetal kick count with one or more of the objective tests would provide the optimal results in fetal surveillance when applied in a flexible manner according to clinical circumstances. It has been pointed out clearly that the different tests measure different functions and that they are all time-related.[33] The three objective fetal surveillance tests cannot by themselves identify all pregnancies that have an adverse outcome.

Table 3. Medical Factors that Determine the Frequency and Methods of Fetal Surveillance in Diabetic Pregnancies

- **Past-obstetrical history**
  - Stillbirth
  - Intervention for antepartum or intrapartum fetal distress
  - Fetal asphyxia at birth
- **Index pregnancy**
  - Number of fetuses
  - Presence of obstetrical complications e.g. infection
  - Presence of other medical complications e.g. chronic hypertension
  - Fetal size (excessive or restricted growth)
- **Severity of diabetes**
  - Gestation at diagnosis in GDM, and type of diabetes in PGDM
  - Need for insulin
  - Degree and stability of glycaemic control
  - Complications of poor glycaemic control e.g. polyhydramnios
  - Evidence of underlying vasculopathy

This is because the development of other complications, such as pre-eclampsia and preterm labour, as well as maternal factors, such as nulliparity and drug abuse, can also be associated with adverse outcomes even when all three tests are considered normal. An experienced obstetrician is needed to integrate the results of these tests with pregnancy course, and to determine the frequency and optimal approach to fetal surveillance in individual pregnancies.

Most importantly, however, one must not forget that the ultimate goal of management is to ensure a successful pregnancy outcome, and that fetal surveillance is only a means to this end. Therefore it is prudent to plan ahead the timing and the mode of delivery, especially when intensive fetal surveillance is indicated. Certainly, one should consider and discuss with the patient the plan for delivery when the pregnancy has progressed to 39 weeks gestation even though there is no evidence as yet of fetal compromise or obstetric complications. This is because of the tendency towards sudden and unexpected fetal distress or other intrapartum complications in these pregnancies.

REFERENCES

1. Whittle MJ, Anderson D, Lowensohn RI, Mestman JH, Paul RH, Goebelsmann U. Estriol in pregnancy VI experience with unconjugated plasma estriol assays and antepartum fetal heart rate testing in diabetic pregnancies. Am J Obstet Gynecol 1979;135:764-772.
2. Hawthorne G, Snodgrass A, Tunbridge M. Outcome of diabetic pregnancy and glucose intolerance in pregnancy: an audit of fetal loss in Newcastle General Hospital 1977-1990. Diabetes Res Clin Pract 1994;25:183-190.
3. Beischer NA, Wein P, Sheedy M, Steffen B. Identification and treatment of women with hyperglycaemia diagnosed during pregnancy can significantly reduce perinatal mortality rates. Aust NZ J Obstet Gynaecol 1996;36:239-247.
4. World Health Organization Expert Committee on Diabetes Mellitus. Second Report. Technical Report Series 646. World Health Organization 1980;8-12.
5. Deerochanawong C, Putiyanun C, Wongsuryrat M, Serirat S, Jinayon P. Comparison of National Diabetes Data Group & World Health Organization criteria for detecting gestational diabetes mellitus. Diabetologia 1996;39:1070-1073.
6. Lao TT, Lee CP. Gestational "impaired glucose tolerance": should the cutoff be raised to 9 mmol/L^{-1}? Diabet Med 1998;15:25-29.
7. Lau TK, Li CY. A perinatal audit of stillbirths in a teaching hospital in Hong Kong. Aust NZ J Obstet Gynaecol 1994;34:416-421.
8. Teramo K, Ämmälä P, Ylinen K, Raivio KO. Pathologic fetal heart rate associated with poor metabolic control in diabetic pregnancies. Obstet Gynecol 1983;61:559-565.
9. Serra-Serra V, Camara R, Sarrión P, et al. Effects of prandial glycaemic changes on objective fetal heart rate parameters. Acta Obstet Gynecol Scand 2000;79:953-957.
10. Kramer DC, Fleischer FS, Marx GF. Fetal bradycardia resulting from maternal hypoglycaemia. A report of two cases. J Reprod Med 1995;40:394-396.
11. Björklund AO, Adamson UKC, Almström NHH, et al. Effects of hypoglycaemia on fetal heart activity and umbilical artery Doppler velocity waveforms in pregnant women with insulin-dependent diabetes mellitus. Br J Obstet Gynaecol 1996;103:413-420.
12. Manning FA. Fetal medicine. Principles and practice. Norwalk: Appleton & Lange; 1995.
13. Roberts AB, Stubbs SM, Mooney R, Cooper D, Brudenell JM, Cambell S. Fetal activity in pregnancies complicated by maternal diabetes mellitus. Br J Obstet Gynaecol 1980;87:485-489.
14. Boddy K, Dawes G. Fetal breathing. Br Med Bull 1975;31:3-7.
15. Devoe LD, Youssef AA, Castillo RA, Croom CS. Fetal biophysical activities in third-trimester pregnancies complicated by diabetes mellitus. Am J Obstet Gynecol 1994;171:298-305.
16. Johnson JM, Lange IR, Harman CR, Torchia MG, Manning FA. Biophysical profile scoring in the management of the diabetic pregnancy. Obstet Gynecol 1988;72:841-846.
17. Landon MB, Gabbe SG, Bruner JP, Ludmir J. Doppler umbilical artery velocimetry in pregnancy complicated by insulin-dependent diabetes mellitus. Obstet Gynecol 1989;73:961-965.
18. Zimmermann P, Kujansuu E, Tuimala R. Doppler velocimetry of the umbilical artery in

pregnancies complicated by insulin-dependant diabetes mellitus. Eur J Obstet Gynecol Reprod Biol 1992;47:85-93.
19. Grunewald C, Divon M, Lunell NO. Doppler velocimetry in last trimester pregnancy complicated by insulin-dependent diabetes mellitus. Acta Obstet Gynecol Scand 1996;75:804-808.
20. Salvesen DR, Higueras MT, Mansur CA, Freeman J, Brudenell JM, Nicolaides K. Placental and fetal Doppler velocimetry in pregnancies complicated by maternal diabetes mellitus. Am J Obstet Gynecol 1993;168:645-652.
21. Bracero LA, Schulman H, Fleischer A, Farmakides G, Rochelson B. Umbilical artery velocimetry in diabetes and pregnancy. Obstet Gynecol 1986;68:654-658.
22. Bracero LA, Jovanovic L, Rochelson B, Bauman W, Farmakides G. Significance of umbilical and uterine artery velocimetry in the well-controlled pregnant diabetic. J Reprod Med 1989;34:273-276.
23. Degani S, Paltieli Y, Gonen R, Sharf M. Fetal internal carotid artery pulsed Doppler flow velocity waveforms and maternal plasma glucose levels. Obstet Gynecol 1991;77:379-381.
24. Crandell SS, Fisher DJ, Morriss FH Jr. Effects of ovine maternal hyperglycaemia on fetal regional blood flows and metabolism. Am J Physiol 1985;249:E454-E460.
25. Kuhn DC, Crawford MA, Stuart MJ, Botti JJ, Derners LM. Alterations in transfer and lipid distribution of arachidonic acid in placentas of diabetic pregnancies. Diabetes 1990;39:914-918.
26. Johnstone FD, Steel JM, Haddad NG, Hoskins PR, Greer IA, Chambers S. Doppler umbilical artery flow velocity waveforms in diabetic pregnancy. Br J Obstet Gynaecol 1992;99:135-140.
27. Bracero LA, Beneck D, Schulman H. Doppler velocimetry, placental morphology and outcome in insulin-dependent diabetes. Ultrasound Obstet Gynecol 1993;3:236-239.
28. Fadda GM, Cherchi PL, D'Antona D, et al. Umbilical artery pulsatility index in pregnancies complicated by insulin-dependent diabetes mellitus without hypertension. Gynecol Obstet Invest 2001;51:173-177.
29. Fadda GM, D'Antona D, Ambrosini G, et al. Placental and fetal pulsatility indices in gestational diabetes mellitus. J Reprod Med 2001;46:365-370.
30. Landon MB. Gabbe SG. Antepartum fetal surveillance in gestational diabetes mellitus. Diabetes 1985;34(Suppl 2):50-54.
31. Landon MB, Langer O, Gabbe SG, Schiek C, Brustman L. Fetal surveillance in pregnancies complicated by insulin-dependent diabetes mellitus. Am J Obstet Gynecol 1992;167:617-621.
32. Kjos SL, Leung A, Henry OA, Victor MR, Paul RH, Medearis AL. Antepartum surveillance in diabetic pregnancies: predictors of fetal distress in labor. Am J Obstet Gynecol 1995;173:1532-9.
33. Bracero LA, Figueroa R, Byrne DW, Han HJ. Comparison of umbilical Doppler velocimetry, nonstress testing, and biophysical profile in pregnancies complicated by diabetes. J Ultrasound Med 1996;15:301-308.

About the Author

Professor Lao is Head of the High Risk Obstetrics Team,[3]Department of Obstetrics and Gynaecology, Queen Mary Hospital, The University of Hong Kong, Hong Kong SAR, China.