PRENATAL DIAGNOSIS
Prenat Diagn 2002; **22**: 308–315.
Published online in Wiley InterScience (www.interscience.wiley.com). **DOI:** 10.1002/pd.308

Increased fetal nuchal translucency at 11–14 weeks

Kypros H. Nicolaides*, Victoria Heath and Simona Cicero

Harris Birthright Research Centre for Fetal Medicine, King's College Hospital, King's College London, London, UK

Nuchal translucency (NT) is the sonographic appearance of a subcutaneous collection of fluid behind the fetal neck. The measurement of fetal NT thickness at the 11–14-week scan has been combined with maternal age to provide an effective method of screening for trisomy 21; for an invasive testing rate of 5%, about 75% of trisomic pregnancies can be identified. When maternal serum free-β human chorionic gonadotrophin (β-hCG) and pregnancy-associated plasma protein-A (PAPP-A) at 11–14 weeks are also taken into account, the detection rate of chromosomal defects is about 90%. Increased NT can also identify a high proportion of other chromosomal abnormalities and is associated with major defects of the heart and great arteries, and a wide range of skeletal dysplasias and genetic syndromes. In monochorionic twins, discordancy for increased NT is an early marker of twin-to-twin transfusion syndrome (TTTS). As with the introduction of any new technology into routine clinical practice, it is essential that those undertaking the 11–14-week scan are adequately trained and their results are subjected to rigorous audit. Copyright © 2002 John Wiley & Sons, Ltd.

KEY WORDS: nuchal translucency (NT); chromosomal defects; fetal abnormalities; ultrasonography; screening; free-β human chorionic gonadotrophin (β-hCG); pregnancy-associated plasma protein-A (PAPP-A)

INTRODUCTION

The early pregnancy scan was initially introduced with the primary intention of measuring the fetal crown–rump length (CRL) to achieve accurate pregnancy dating. During the last decade, however, improvement in the resolution of ultrasound machines has made it possible to describe the normal anatomy of the fetus and diagnose or suspect the presence of a wide range of fetal defects in the first trimester of pregnancy. An important component of the 11–14-week scan is measurement of fetal nuchal translucency (NT) thickness (Figure 1) which provides effective screening for chromosomal abnormalities, major defects of the heart and great arteries, and a wide range of skeletal dysplasias and genetic syndromes.

MEASUREMENT OF NT

In the measurement of fetal NT it is essential that the same criteria are used to achieve uniformity of results among different operators:

1. All sonographers performing fetal scans should be appropriately trained and their results subjected to rigorous audit. The Fetal Medicine Foundation, under the auspices of the International Society of Ultrasound in Obstetrics and Gynecology, has introduced a Certificate of Competence in the 11–14-week scan, which is awarded to those sonographers who can perform the scan to a high standard and can demonstrate a good knowledge of the diagnostic features and management of the conditions identified by this scan.
2. The ultrasound equipment must be good quality, it should have a video-loop function and the calipers should be able to provide measurements to one decimal point.
3. NT can be measured successfully by transabdominal ultrasound examination in about 95% of cases; in the others, it is necessary to perform transvaginal sonography.
4. The ability to measure NT and obtain reproducible results improves with training; good results are achieved after 80 and 100 scans for the transabdominal and the transvaginal routes, respectively (Braithwaite *et al*., 1996a). The intra-observer and inter-observer differences in measurements are less than 0.5 mm in 95% of cases (Pandya *et al*., 1995).
5. The minimum fetal CRL should be 45 mm and the maximum 84 mm. The optimal gestational age for measurement of fetal NT is 11 to 13 + 6 weeks.
6. Fetal NT increases with CRL and therefore it is essential to take gestation into account when determining whether a given translucency thickness is increased (Snijders *et al*., 1998).
7. A good sagittal section of the fetus, as for measurement of fetal CRL, should be obtained and the NT should be measured with the fetus in the neutral position. When the fetal neck is hyperextended the measurement can be increased by 0.6 mm and when the neck is flexed, the measurement can be decreased by 0.4 mm (Whitlow *et al*., 1998)
8. The magnification should be such that each increment in the distance between calipers should be only 0.1 mm. A study, in which rat heart ventricles were measured initially by ultrasound and then by

*Correspondence to: K. H. Nicolaides, Harris Birthright Centre for Fetal Medicine, King's College Hospital, King's College London, Denmark Hill, London SE5 8RX, UK.
E-mail: kypros@fetalmedicine.com

Copyright © 2002 John Wiley & Sons, Ltd.

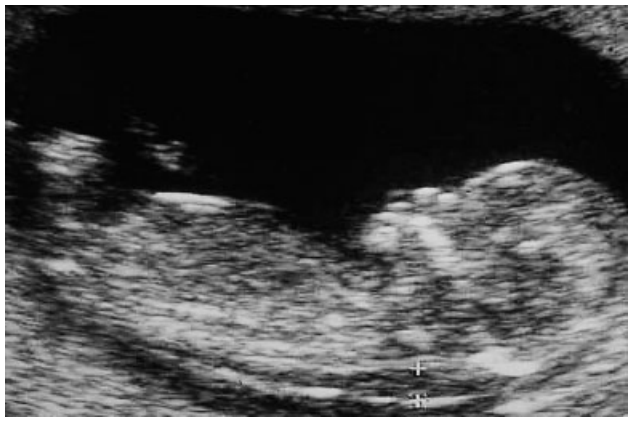

Figure 1—A 11–14-week scan measurement of fetal nuchal translucency (NT) thickness

dissection, has demonstrated that ultrasound measurements can be accurate to the nearest 0.1–0.2 mm (Braithwaite *et al*., 1996b).

9. Care must be taken to distinguish between fetal skin and amnion because, at this gestation, both structures appear as thin membranes (Nicolaides *et al*., 1992). This is achieved by waiting for spontaneous fetal movement away from the amniotic membrane; alternatively, the fetus is bounced off the amnion by asking the mother to cough and/or tapping the maternal abdomen.
10. The maximum thickness of the subcutaneous translucency between the skin and the soft tissue overlying the cervical spine should be measured. During the scan, more than one measurement must be taken and the maximum one should be recorded.
11. The umbilical cord may be around the fetal neck in 5–10% of cases and this finding may produce a falsely increased NT, adding about 0.8 mm to the measurement (Schaefer *et al*., 1998).
12. In such cases, the measurements of NT above and below the cord are different and, in the calculation of risk, it is more appropriate to use the smaller measurement.

The ability to achieve a reliable measurement of NT is dependent on adherence to the criteria outlined above and on the motivation of sonographers. For example, in a screening study in which the time spent in examining patients was less than 3 min and in which 54% of cases were examined before 10 weeks, the sonographers were unable to measure NT in 42% of the cases (Kornman *et al*., 1996). A study comparing the results obtained from hospitals where NT was used in clinical practice (interventional) compared to those from hospitals where they merely recorded the measurements but did not act on the results (observational) reported that, in the interventional group, successful measurement of NT was achieved in 100% of cases and the measurement was >2.5 mm in 2.3% of cases. The respective percentages in the observational group were 85% and 12% (Bower *et al*., 1995). Appropriate training, high motivation and adherence to a standard technique for the measurement of NT are essential prerequisites for good clinical practice.

PATHOPHYSIOLOGY OF INCREASED NT

Possible mechanisms for increased NT include:

1. Cardiac failure in association with abnormalities of the heart and great arteries. Studies involving pathological examination in both chromosomally abnormal and normal fetuses with increased NT at 11–14 weeks have demonstrated a high prevalence of abnormalities of the heart and great arteries (Hyett *et al*., 1997a,b). Doppler ultrasound studies examining ductal flow at 11–14 weeks in fetuses with increased NT reported absent or reverse flow during atrial contraction in about 90% of chromosomally abnormal fetuses and in chromosomally normal fetuses with cardiac defects (Matias *et al*., 1998, 1999). In trisomic fetuses with increased NT there are increased levels of atrial and brain natriuretic peptide mRNA in fetal hearts, suggesting the presence of heart strain (Hyett *et al*., 1996).
2. Venous congestion in the head and neck, due to constriction of the fetal body in amnion rupture sequence or superior mediastinal compression found in diaphragmatic hernia or the narrow chest in skeletal dysplasia (Daskalakis *et al*., 1997; Sebire *et al*., 1997a; Souka *et al*., 1998).
3. Altered composition of the extracellular matrix. Many of the component proteins of the extracellular matrix are encoded on chromosomes 21, 18 or 13. Immunohistochemical studies of the skin of chromosomally abnormal fetuses have demonstrated specific alterations of the extracellular matrix which may be attributed to gene dosage effects (von Kaisenberg *et al*., 1998a,b). Altered composition of the extracellular matrix may also be the underlying mechanism for increased fetal NT in an expanding number of genetic syndromes, which are associated with alterations in collagen metabolism (such as achondrogenesis type II), abnormalities of fibroblast growth factor receptors (such as achondroplasia and thanatophoric dysplasia) or disturbed metabolism of peroxisome biogenesis factor (such as Zellweger syndrome).
4. Abnormal or delayed development of the lymphatic system. In normal embryos, the main lymphatics develop from the venous walls, but they subsequently lose their connections with the veins to form a separate lymphatic system, except for the jugulo-axillary sacs, which drain the lymph to the venous system. A possible mechanism for increased translucency is dilatation of the jugular lymphatic sacs, because of developmental delay in the connection with the venous system, or a primary abnormal dilatation or proliferation of the lymphatic channels interfering with a normal flow between the lymphatic and venous systems. In fetuses with Turner syndrome there is hypoplasia of lymphatic vessels (von Kaisenberg *et al*., 1999).
5. Failure of lymphatic drainage due to impaired fetal

Copyright © 2002 John Wiley & Sons, Ltd.

movements in various neuromuscular disorders, such as fetal akinesia deformation sequence (Hyett *et al.*, 1997c).
6. Fetal anemia or hypoproteinemia (Lam *et al.*, 1999).
7. Congenital infection, acting through anemia or cardiac dysfunction (Petrikovsky *et al.*, 1996; Sebire *et al.*, 1997b).

NT AND CHROMOSOMAL DEFECTS

In 1866, Langdon Down reported that the skin of individuals with trisomy 21 appears to be too large for their body. In the 1990s, it was realized that the excess skin of individuals with Down syndrome can be visualized by ultrasonography as increased NT in the first 3 months of intrauterine life (Nicolaides *et al.*, 1992). Fetal NT at the 11–14-week scan has been combined with maternal age to provide an effective method of screening for trisomy 21; for an invasive testing rate of 5%, about 75% of trisomic pregnancies can be identified (Snijders *et al.*, 1998). When maternal serum free-β-human chorionic gonadotrophin (β-hCG) and pregnancy-associated plasma protein-A (PAPP-A) at 11–14 weeks are also taken into account, the detection rate of chromosomal defects is about 90% (Spencer *et al.*, 1999). Furthermore, the development of new methods of biochemical testing, within 30 min of taking a blood sample, has now made it possible to introduce one-stop clinics for assessment of risk (OSCAR).

Every woman has a risk that her fetus/baby has a chromosomal defect. In order to calculate the individual risk, it is necessary to take into account the *background risk* (which depends on maternal age, gestation and previous history of chromosomal defects) and multiply this by a series of factors, which depend on a series of screening tests carried out during the course of the pregnancy. Every time a test is carried out the *background risk is multiplied by the test factor* to calculate a new risk, which then becomes the background risk for the next test (Snijders and Nicolaides, 1996). This process is called *sequential screening*. With the introduction of OSCAR, this can all be achieved in one session at about 12 weeks of pregnancy (Figure 2).

Maternal age and gestation

The risk for many of the chromosomal defects increases with maternal age (Hecht and Hook, 1994). Additionally, because fetuses with chromosomal defects are more likely to die *in utero* than normal fetuses, the risk decreases with gestation. The rates of fetal death in trisomy 21 between 12 weeks (when NT screening is carried out) and term is 30% and between 16 weeks (when second trimester serum biochemistry screening is carried out) and term is 20% (Halliday *et al.*, 1995; Snijders *et al.*, 1995, 1999a; Morris *et al.*, 1999).

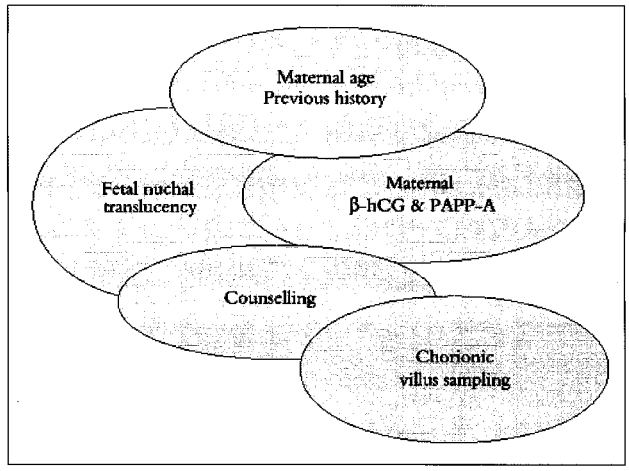

Figure 2—Sequential screening process

Fetal NT

In a multicentre study under the auspices of The Fetal Medicine Foundation, 96127 singleton pregnancies were examined, including 326 with trisomy 21 and 325 with other chromosomal abnormalities (Snijders *et al.*, 1998). In each pregnancy, the fetal CRL and NT were measured and the risk of trisomy 21 was calculated from the maternal age and gestational age-related prevalence, multiplied by a likelihood ratio depending on the deviation in NT from normal (Figures 3–5). The larger the NT, the higher the multiplying factor becomes and therefore the higher the new risk. In contrast, the smaller the NT measurement, the smaller the multiplying factor becomes and therefore the lower the new risk (Nicolaides *et al.*, 1999). The distribution of risks was determined and the sensitivity of a cut-off risk of 1 in 300 was calculated 62. The median gestation at the time of screening was 12 weeks (range 10–14 weeks) and the median maternal age was 31 years (range 14–49 years). The fetal NT was above the 95th percentile for CRL in 72% of the trisomy 21 pregnancies. The estimated risk for trisomy 21 based on maternal age and fetal NT was above 1 in 300 in 8.3% of the normal pregnancies and in 82% of those with trisomy 21. For a screen-positive rate of 5%, the sensitivity was 77% [95% confidence interval (CI) 72–82%].

Screening for chromosomal defects in the first trimester has the advantage of earlier prenatal diagnosis and consequently less traumatic termination of pregnancy for those couples who choose this option. A potential disadvantage is that earlier screening preferentially identifies those chromosomally abnormal pregnancies that are destined to miscarry. Approximately 30% of affected fetuses die between 12 weeks gestation and term (Snijders *et al.*, 1999). This issue of preferential intrauterine lethality of chromosomal defects is, of course, a potential criticism of all methods of prenatal screening, including second trimester maternal serum biochemistry; the estimated rate of intrauterine lethality between 16 weeks and term is about 20% (Snijders *et al.*, 1999). In The Fetal

Copyright © 2002 John Wiley & Sons, Ltd.

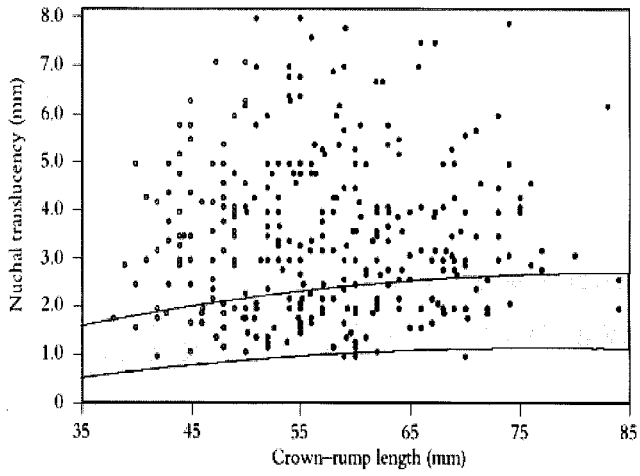

Figure 3—Nuchal translucency (NT) measurements and crown–rump length (CRL) (mm)

Medicine Foundation Multicenter Project it was estimated that assessment of risk by a combination of maternal age and fetal NT, followed by invasive diagnostic testing for those with a risk of 1 in 300 or more, and selective termination of affected fetuses would have reduced the potential livebirth prevalence of trisomy 21 by at least 78% (Snijders *et al.*, 1998).

NT and other chromosomal defects

In The Fetal Medicine Foundation Multicenter Project there were 325 cases with chromosomal abnormalities other than trisomy 21 (Snijders *et al.*, 1998). In 71% of these, the fetal NT was above the 95th percentile of the normal range for CRL. Furthermore, in 78% of the pregnancies, the estimated risk for trisomy 21, based on maternal age and fetal NT, was more than 1 in 300.

In addition to increased NT, there are other characteristic sonographic findings in these fetuses. In trisomy 18, there is early onset intrauterine growth restriction (IUGR), relative bradycardia and, in about 30% of the cases, there is an associated exomphalos (Sherrod *et al.*, 1997). Trisomy 13 is characterized by fetal tachycardia, observed in about two-thirds of the cases, early-onset IUGR, and holoprosencephaly or exomphalos in about 30% of the cases (Snijders *et al.*, 1999b). Turner syndrome is characterized by fetal tachycardia, observed in about 50% of the cases, and early-onset IUGR (Sebire *et al.*, 1998). In triploidy, there is early onset asymmetrical IUGR, relative bradycardia, holoprosencephaly, exomphalos or posterior fossa cyst in about 40% of cases, and molar changes in the placenta in about one-third of cases (Jauniaux *et al.*, 1997).

Fetal NT and maternal serum biochemistry

In trisomy 21 during the first trimester of pregnancy, the maternal serum concentration of free β-hCG is higher than in chromosomally normal fetuses whereas

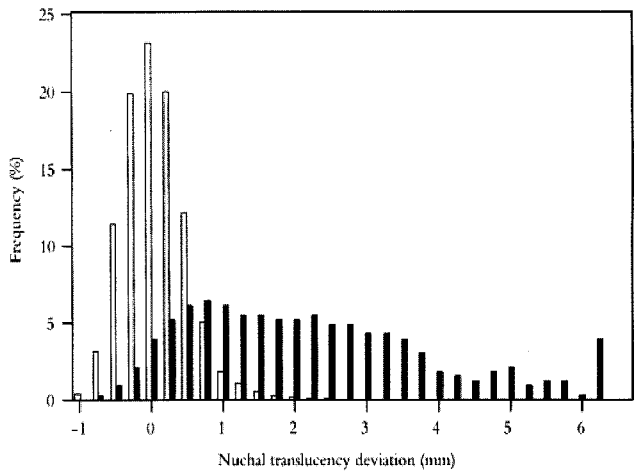

Figure 4—Nuchal translucency (NT) deviation and frequency

Copyright © 2002 John Wiley & Sons, Ltd.

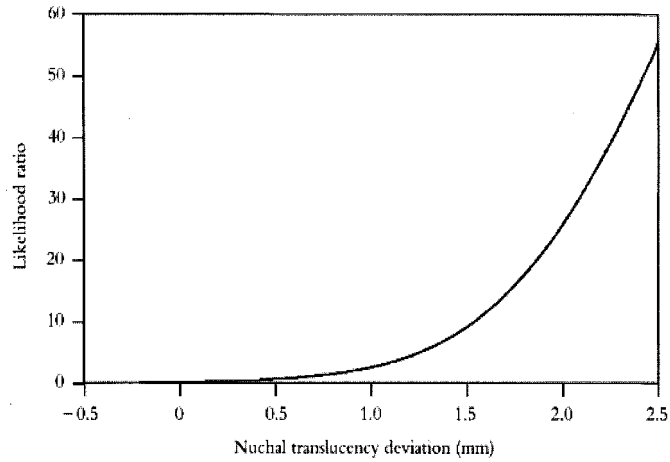

Figure 5—Nuchal translucency (NT) and likelihood ratio

PAPP-A is lower. There is no significant association between fetal NT and maternal serum free β-hCG or PAPP-A in either trisomy 21 or chromosomally normal pregnancies (Brizot *et al.*, 1994, 1995; Spencer *et al.*, 1999). The estimated detection rate for trisomy 21 by combination of maternal age, fetal NT and maternal serum PAPP-A and free β-hCG is about 90% for a screen-positive rate of 5% (Spencer *et al.*, 1999).

In trisomies 18 and 13 maternal serum free β-hCG and PAPP-A are decreased (Tul *et al.*, 1999; Spencer *et al.*, 2000a). In cases of sex chromosomal anomalies maternal serum free β-hCG is normal and PAPP-A is low (Spencer *et al.*, 2000b). Triploidy, in which the additional chromosome set is of paternal origin (diandric), is associated with a partially molar placenta; maternal serum free β-hCG is greatly increased, whereas PAPP-A is mildly decreased (Spencer *et al.*, 2000c). Digynic triploidy, characterized by a small normal-looking placenta and severe asymmetrical fetal growth restriction, is associated with markedly decreased maternal serum free β-hCG and PAPP-A. Screening by a combination of fetal NT and maternal serum PAPP-A and free β-hCG can identify about 90% of all these chromosomal abnormalities for a screen-positive rate of 1%.

NT followed by second trimester biochemistry

In women having second trimester biochemical testing following first trimester NT screening (with or without maternal serum biochemistry), the *background* risk needs to be adjusted to take into account the first trimester screening results. Since first trimester screening identifies almost 90% of trisomy 21 pregnancies, second trimester biochemistry will identify – at best – 6% (60% of the residual 10%) of the affected pregnancies, with doubling of the overall invasive testing rate (from 5% to 10%). It is theoretically possible to use various statistical techniques to combine NT with different components of first and second trimester biochemical testing. One such hypothetical model has combined first trimester NT and PAPP-A with second trimester free β-hCG, estriol and inhibin A, claiming a potential sensitivity of 94% for a 5% false-positive rate (Wald *et al.*, 1999). Even if the assumptions made in this statistical technique are valid, it is unlikely that it will gain widespread clinical acceptability (Copel and Bahado-Singh, 1999).

Two studies have reported on the impact of first trimester screening by NT on second trimester serum biochemical testing. In one study, the proportion of affected pregnancies in the screen-positive group (positive predictive value) of screening by the double test in the second trimester was 1 in 40. After the introduction of screening by NT, 83% of trisomy 21 pregnancies were identified in the first trimester and the positive predictive value of biochemical screening decreased to 1 in 200 (Kadir and Economides, 1997). In the second study, first trimester screening by NT identified 71% of trisomy 21 pregnancies for a screen-positive rate of 2%, and the positive predictive value of second trimester screening by the quadruple test was only 1 in 150 (Thilaganathan *et al.*, 1997).

NT followed by second trimester ultrasonography

In the mid-trimester scan minor fetal defects or markers are common and they are not usually associated with any handicap, unless there is an associated chromosomal abnormality. Routine karyotyping of all pregnancies with these markers would have major implications, both in terms of miscarriage and in economic costs. It is best to base counseling on an individual estimated risk for a chromosomal abnormality, rather than the arbitrary advice that invasive testing is recommended because the risk is 'high'. The estimated risk can be derived by multiplying the *background risk* (based on maternal age, gestational age, history of

Copyright © 2002 John Wiley & Sons, Ltd.

previously affected pregnancies and, where appropriate, the results of previous screening by NT and/or biochemistry in the current pregnancy) by the likelihood ratio of the specific defect (Snijders and Nicolaides, 1996). On the basis of existing data, for apparently isolated markers, the estimated likelihood ratio for trisomy 21 is 15 for nuchal edema, 4 for short femur and for echogenic foci in the heart, 3 for hyperechogenic bowel, and 1.5 for choroid plexus cysts and for mild hydronephrosis (Nicolaides *et al.*, 1999).

There are no data on the interrelation between these second trimester ultrasound markers and NT at 11–14 weeks or first and second trimester biochemistry. However, there is no obvious physiological reason for such an interrelation and it is therefore reasonable to assume that they are independent. Consequently, in estimating the risk in a pregnancy with a marker, it is logical to take into account the results of previous screening tests. For example, in a 20-year-old woman at 20 weeks of gestation (background risk of 1 in 1295), who had a 11–14 week assessment by NT measurement that resulted in a five-fold reduction in risk (to about 1 in 6475), after the diagnosis of mild hydronephrosis at the 20-week scan, the estimated risk has increased by a factor of 1.5 to 1 in 4317. In contrast, for the same ultrasound finding of fetal mild hydronephrosis in a 40-year-old woman (background risk of 1 in 82), who did not have NT or biochemistry screening, the new estimated risk is 1 in 55.

There are some exceptions to this process of sequential screening, which assumes independence between the findings of different screening results. The findings of nuchal edema or a cardiac defect at the midtrimester scan cannot be considered independently of NT screening at 11–14 weeks. Similarly, hyperechogenic bowel (which may be due to intra-amniotic bleeding) and relative shortening of the femur (which may be due to placental insufficiency) may well be related to serum biochemistry (high free β-hCG and inhibin-A and low estriol may be markers of placental damage) and can, therefore, not be considered independently in estimating the risk for trisomy 21.

NT AND FETAL DEFECTS

Extensive studies have now established that, in chromosomally normal fetuses, increased NT is associated with a wide range of fetal defects and genetic syndromes and the prevalence of fetal abnormalities increases with NT: 3 mm, 2.4%; 4 mm, 7.1%; 5 mm, 12.3% 6 mm, 16.7%; 7 mm, 35.6% (Souka *et al.*, 1998). Furthermore, increased NT is associated with increased rates of miscarriage and perinatal death. However, it should be emphasized to the parents that increased NT *per se* does not constitute a fetal abnormality and, once chromosomal defects have been excluded, about 90% of pregnancies with fetal NT below 4.5–6.4 mm and 6.5 mm or more are about 80% and 45%, respectively (Souka *et al.*, 1998).

Increased NT and cardiac defects

Abnormalities of the heart and great arteries are the most common congenital defects and the birth prevalence is 5–10 per 1000. In general, about half are either lethal or require surgery and half are asymptomatic. The first two groups are referred to as major. Specialist echocardiography at around 20 weeks of gestation can identify most of the major cardiac defects, but the main challenge in prenatal diagnosis is to identify the high-risk group for referral to specialist centers. Currently, screening is based on examination of the four-chamber view of the heart at the 20-week scan, but this identifies only about 25% of the major cardiac defects (Tegnander *et al.*, 1995). There is now evidence that measurement of NT may provide more effective screening for major abnormalities of the heart and great arteries.

There are several case reports or small series on the sonographic diagnosis of cardiac defects at the 11–14-week scan, in a total of 21 fetuses with major cardiac defects, 17 (81%) had increased NT (Bronshtein *et al.*, 1990; Gembruch *et al.*, 1990, 1993; Achiron *et al.*, 1994). A retrospective study of 29 153 chromosomally normal singleton pregnancies identified major defects of the heart and great arteries in 50 cases (Hyett *et al.*, 1999). The prevalence of defects increased with NT from 0.8 per 1000 for those with translucency below the 95th percentile to 63.5 per 1000 for translucency above the 99th percentile, and 56% were in the subgroup with translucency above the 95th percentile.

In a prospective study of 398 chromosomally normal fetuses with a NT measurement above the 99th percentile ($\geqslant$3.5 mm), specialist fetal echocardiography was carried out (Zosmer *et al.*, 1999). Major cardiac defects were present in 29 (7.6%) cases and, in 28 of these, the diagnosis was made by prenatal echocardiography. The prevalence of cardiac defects increased from 3% in those with a NT of 3.5–5.4 mm to 15% in those with a measurement of 5.5 mm or more.

The clinical implication of these findings is that increased NT constitutes an indication for specialist fetal echocardiography. Certainly, the overall prevalence of major cardiac defects in such a group of fetuses (about 2%) is similar to that found in pregnancies affected by maternal diabetes mellitus or with a history of a previously affected offspring, which are well accepted indications for fetal echocardiography. At present, there may not be sufficient facilities for specialist fetal echocardiography to accommodate the potential increase in demand if the 95th percentile of NT is used as the cut-off for referral. In contrast, a cut-off of the 99th percentile would result in only a small increase in workload and, in this population, the prevalence of major cardiac defects would be very high (about 6%).

Patients identified by NT scanning as being at high risk for cardiac defects need not wait until 20 weeks for specialist echocardiography. Improvements in the resolution of ultrasound machines have now made it

Copyright © 2002 John Wiley & Sons, Ltd.

possible to undertake detailed cardiac scanning in the first trimester of pregnancy (Gembruch *et al*., 1993; Carvalho *et al*., 1998; Zosmer *et al*., 1999). A specialist scan from 14 weeks can effectively reassure the majority of parents that there is no major cardiac defect. In the cases with a major defect, the early scan can either lead to the correct diagnosis or at least raise suspicions so that follow-up scans are carried out.

MULTIPLE PREGNANCY

Screening for chromosomal defects

In dichorionic twin pregnancies, the sensitivity and false-positive rate of fetal NT in screening for trisomy 21 are similar to those in singleton pregnancies (Sebire *et al*., 1996). Therefore, effective screening and diagnosis of major chromosomal abnormalities can be achieved in the first trimester, allowing the possibility of earlier and therefore safer selective fetocide for those parents that choose this option.

In monochorionic pregnancies the number of cases examined is still too small to draw definite conclusions as to whether, in the calculation of risk of trisomy 21 in monochorionic pregnancies, the NT of the fetus with the largest or the smallest measurement (or the average of the two) should be considered.

Twin-to-twin transfusion syndrome (TTTS)

Ultrasonographic features of the underlying hemodynamic changes in severe twin-to-twin transfusion syndrome (TTTS) may be present from as early as 11–14 weeks of gestation and manifest as increased NT thickness in one or both of the fetuses. In a study of 132 monochorionic twin pregnancies, including 16 that developed severe TTTS syndrome at 15–22 weeks of gestation, increased NT (above the 95th percentile of the normal range) at the 11–14-week scan was associated with a four-fold increase in risk for the subsequent development of severe TTTS syndrome (Sebire *et al*., 1997c). It is possible that increased NY thickness in the recipient fetus may be a manifestation of heart failure due to hypervolemic congestion. With advancing gestation and the development of diuresis that would tend to correct the hypervolemia and reduce heart strain, both the congestive heart failure and NT resolve.

REFERENCES

Achiron R, Rotstein Z, Lipitz S, Mashiach S, Hegesh J. 1994. First-trimester diagnosis of fetal congenital heart disease by transvaginal ultrasonography. *Obstet Gynecol* **84** (1): 69–72.

Bower S, Chitty L, Bewley S, *et al.* 1995. First trimester nuchal translucency screening of the general population: data from three centres (Abstract). Presented at the 27th British Congress of Obstetrics and Gynecology, Royal College of Obstetrics and Gynecology, Dublin, Eire.

Braithwaite JM, Kadir RA, Pepera TA, Morris RW, Thompson PJ, Economides DL. 1996a. Nuchal translucency measurement: training of potential examiners. *Ultrasound Obstet Gynecol* **8** (3): 192–195.

Braithwaite JM, Morris RW, Economides DL. 1996b. Nuchal translucency measurements: frequency distribution and changes with gestation in a general population. *Br J Obstet Gynaecol* **103** (12): 1201–1204.

Brizot ML, Snijders RJM, Bersinger NA, Kuhn P, Nicolaides KH. 1994. Maternal serum pregnancy-associated plasma protein A and fetal nuchal translucency thickness for the prediction of fetal trisomies in early pregnancy. *Obstet Gynecol* **84** (6): 918–922.

Brizot ML, Snijders RJM, Butler J, Bersinger NA, Nicolaides KH. 1995. Maternal serum hCG and fetal nuchal translucency thickness for the prediction of fetal trisomies in the first trimester of pregnancy. *Br J Obstet Gynaecol* **102** (2): 127–132.

Bronshtein M, Siegler E, Yoffe N, Zimmer EZ. 1990. Prenatal diagnosis of ventricular septal defect and overriding aorta at 14 weeks' gestation, using transvaginal sonography. *Prenat Diagn* **10** (11): 697–702.

Carvalho JS, Moscoso G, Ville Y. 1998. First-trimester transabdominal fetal echocardiography. *Lancet* **351** (9108): 1023–1027.

Copel J, Bahado-Singh RO. 1999. Prenatal screening for Down syndrome – a search for the family's values. *N Engl J Med* **341** (7): 521–522.

Daskalakis G, Sebire NJ, Jurkovic D, Snijders RJM, Nicolaides KH. 1997. Body stalk anomaly at 10–14 weeks of gestation. *Ultrasound Obstet Gynecol* **10** (6): 416–418.

Gembruch U, Knopfle G, Chatterjee M, Bald R, Hansmann M. 1990. First-trimester diagnosis of fetal congenital heart disease by transvaginal two-dimensional and Doppler echocardiography. *Obstet Gynecol* **75** (3 Part 2): 496–498.

Gembruch U, Knopfle G, Bald R, Hansmann M. 1993. Early diagnosis of fetal congenital heart disease by transvaginal echocardiography. *Ultrasound Obstet Gynecol* **3**: 310–317.

Halliday JL, Watson LF, Lumley J, Danks DM, Sheffield LJ. 1995. New estimates of Down syndrome risks at chorionic villus sampling, amniocentesis, and live birth in woman of advanced maternal age from a uniquely defined population. *Prenat Diagn* **15** (5): 455–465.

Hecht CA, Hook EB. 1994. The imprecision in rates of Down syndrome by 1-year maternal age intervals; a critical analysis of rates used in biochemical screening. *Prenat Diagn* **14** (8): 729–738.

Hyett JA, Brizot ML, von Kaisenberg CS, McKie AT, Farzaneh F, Nicolaides KH. 1996. Cardiac gene expression of atrial natriuretic peptide and brain natriuretic peptide in trisomic fetuses. *Obstet Gynecol* **87** (4): 506–510.

Hyett JA, Moscoso G, Nicolaides KH. 1997a. Abnormalities of the heart and great arteries in first trimester chromosomally abnormal fetuses. *Am J Med Genet* **69** (2): 207–216.

Hyett JA, Perdu M, Sharland GK, Snijders RJ, Nicolaides KH. 1997b. Increased nuchal translucency at 10–14 weeks of gestation as a marker for major cardiac defects. *Ultrasound Obstet Gynecol* **10** (4): 242–246.

Hyett JA, Noble PL, Sebire NJ, Snijders RJM, Nicolaides KH. 1997c. Lethal congenital arthrogryposis presents with increased nuchal translucency at 10–14 weeks of gestation. *Ultrasound Obstet Gynecol* **9** (5): 310–313.

Hyett JA, Perdu M, Sharland GK, Snijders RJ, Nicolaides KH. 1999. Using fetal nuchal translucency to screen for major congenital cardiac defects at 10–14 weeks of gestation: population based cohort study. *BMJ* **318** (7176): 81–85.

Jauniaux E, Brown R, Snijders RJ, Noble P, Nicolaides KH. 1997. Early prenatal diagnosis of triploidy. *Am J Obstet Gynecol* **176** (3): 550–554.

Kadir RA, Economides DL. 1997. The effect of nuchal translucency measurement on second trimester biochemical screening for Down syndrome. *Ultrasound Obstet Gynecol* **9** (4): 244–247.

Kornman LH, Morssink LP, Beekhuis JR, DeWolf BT, Heringa MP, Mantingh A. 1996. Nuchal translucency cannot be used as a screening test for chromosomal abnormalities in the first trimester of pregnancy in a routine ultrasound practice. *Prenat Diagn* **16** (9): 797–805.

Lam YH, Tang MH, Lee CP, Tse HY. 1999. Nuchal translucency in fetuses affected by homozygous alpha-thalassemia-1 at 12–13 weeks of gestation. *Ultrasound Obstet Gynecol* **13** (4): 238–240.

Copyright © 2002 John Wiley & Sons, Ltd.

Matias A, Gomes C, Flack N, Montenegro N, Nicolaides KH. 1998. Screening for chromosomal abnormalities at 10–14 weeks: the role of ductus venosus blood flow. *Ultrasound Obstet Gynecol* **12** (6): 380–384.

Matias A, Huggon I, Areias JC, Montenegro N, Nicolaides KH. 1999. Cardiac defects in chromosomally normal fetuses with abnormal ductus venosus blood flow at 10–14 weeks. *Ultrasound Obstet Gynecol* **14** (5): 307–310.

Morris JK, Wald NJ, Watt HC. 1999. Fetal loss in Down syndrome pregnancies. *Prenat Diagn* **19** (2): 412–145.

Nicolaides KH, Azar G, Byrne D, Mansur C, Marks K. 1992. Fetal nuchal translucency: ultrasound screening for chromosomal defects in first trimester of pregnancy. *BMJ* **304** (6831): 867–869.

Nicolaides KH, Sebire NJ, Snijders RJM. 1999. Nuchal translucency and chromosomal defects. In Nicolaides KH (ed.). *The 11–14-Week Scan: The Diagnosis of Fetal Abnormalities*. Parthenon Publishing: London, UK; 3–65.

Pandya PP, Altman DG, Brizot ML, Pettersen H, Nicolaides KH. 1995. Repeatability of measurement of fetal nuchal translucency thickness. *Ultrasound Obstet Gynecol* **5** (5): 334–337.

Petrikovsky BM, Baker D, Schneider E. 1996. Fetal hydrops secondary to human parvovirus infection in early pregnancy. *Prenat Diagn* **16** (4): 342–344.

Schaefer M, Laurichesse-Delmas H, Ville Y. 1998. The effect of nuchal cord on nuchal translucency measurement at 10–14 weeks. *Ultrasound Obstet Gynecol* **11** (4): 271–273.

Sebire NJ, Snijders RJM, Hughes K, Sepulveda W, Nicolaides KH. 1996. Screening for trisomy 21 in twin pregnancies by maternal age and fetal nuchal translucency thickness at 10–14 weeks of gestation. *Br J Obstet Gynaecol* **103** (10): 999–1003.

Sebire NJ, Snijders RJ, Davenport M, Greenough A, Nicolaides KH. 1997a. Fetal nuchal translucency thinkness at 10–14 weeks' gestation and congenital diaphragmatic hernia. *Obstet Gynecol* **90** (6): 943–946.

Sebire NJ, Bianco D, Snijders RJM, Zuckerman M, Nicolaides KH. 1997b. Increased fetal nuchal translucency thickness at 10–14 weeks: is screening for maternal–fetal infection necessary? *Br J Obstet Gynaecol* **104** (2): 212–215.

Sebire NJ, D'Ercole C, Hughes K, Carvalho M, Nicolaides KH. 1997c. Increased fetal nuchal translucency thickness at 10–14 weeks of gestation as a predictor of severe twin-to-twin transfusion syndrome. *Ultrasound Obstet Gynecol* **10** (2): 86–89.

Sebire NJ, Snijders RJ, Brown R, Southall T, Nicolaides KH. 1998. Detection of sex chromosome abnormalities by nuchal translucency screening at 10-14 weeks. *Prenat Diagn* **18** (6): 581–584.

Sherrod C, Sebire NJ, Soares W, Snijders RJ, Nicolaides KH. 1997. Prenatal diagnosis of trisomy 18 at the 10–14-week ultrasound scan. *Ultrasound Obstet Gynecol* **10** (6): 387–390.

Snijders RJM, Sebire NJ, Nicolaides KH. 1995. Maternal age and gestational age-specific risks for chromosomal defects. *Fetal Diagn Ther* **10** (6): 356–367.

Snijders RJ, Nicolaides KH. 1995. Assessment of risks. In *Ultrasound Markers for Fetal Chromosomal Defects*. Parthenon Publishing: London, UK; 63–120.

Snijders RJ, Noble P, Sebine N, Souka A, Nicolaides KH. 1998. UK multicentre project on assessment of risk of trisomy 21 by maternal age and fetal nuchal translucency thickness at 10–14 weeks of gestation. Fetal Medicine Foundation First Trimester Screening Group. *Lancet* **352** (9125): 343–346.

Snijders RJ, Sundberg K, Holzgreve W, Henry G, Nicolaides KH. 1999a. Maternal age and gestation-specific risk for trisomy 21. *Ultrasound Obstet Gynecol* **13** (3): 167–170.

Snijders RJ, Sebire NJ, Nayar R, Souka A, Nicolaides KH. 1999b. Increased nuchal translucency in trisomy 13 fetuses at 10–14 weeks of gestation. *Am J Med Genet* **86** (3): 205–207.

Souka AO, Snijders RJ, Novakov A, Soares W, Nicolaides KH. 1998. Defects and syndromes in chromosomally normal fetuses with increased nuchal translucency thickness at 10–14 weeks of gestation. *Ultrasound Obstet Gynecol* **11** (6): 391–400.

Spencer K, Souter V, Tul N, Snijders R, Nicolaides KH. 1999. A screening program for trisomy 21 at 10–14 weeks using fetal nuchal translucency, maternal serum free beta-human chorionic gonadotropin and pregnancy-associated plasma protein-A. *Ultrasound Obstet Gynecol* **13** (4): 231–237.

Spencer K, Ong C, Skentou H, Liao AW, Nicolaides KH. 2000a. Screening for trisomy 13 by fetal nuchal translucency and maternal serum free beta hCG and PAPP-A at 10–14 weeks of gestation. *Prenat Diagn* **20** (5): 411–416.

Spencer K, Tul N, Nicolaides KH. 2000b. Maternal serum free beta-hCG and PAPP-A in fetal sex chromosome defects in the first trimester. *Prenat Diagn* **20** (5): 390–394.

Spencer K, Liao A, Skentou H, Cicero S, Nicolaides KH. 2000c. Screening for triploidy by fetal nuchal translucency and maternal serum free beta-hCG and PAPP-A at 10–14 weeks gestation. *Prenat Diagn* **20** (6): 495–499.

Tegnander E, Eik-Nes SH, Johansen OJ, Linker DT. 1995. Prenatal detection of heart defects at the routine fetal examination at 18 weeks in a non-selected population. *Ultrasound Obstet Gynecol* **5** (6): 372–380.

Thilaganathan B, Slack A, Wathen NC. 1997. Effect of first-trimester nuchal translucency on second-trimester maternal serum biochemical screening for Down syndrome. *Ultrasound Obstet Gynecol* **10** (4): 261–264.

Tul N, Spencer K, Noble P, Chan C, Nicolaides KH. 1999. Screening for trisomy 18 by fetal nuchal translucency and maternal serum free beta-hCG and PAPP-A at 10–14 weeks of gestation. *Prenat Diagn* **19** (11): 1035–1042.

von Kaisenberg CS, Brand-Saberi B, Christ B, Vallian S, Farzaneh F, Nicolaides KH. 1998a. Collagen type VI gene expression in the skin of trisomy 21 fetuses. *Obstet Gynecol* **91** (3): 319–323.

von Kaisenberg CS, Krenn V, Ludwig M, Nicolaides KH, Brand-Saberi B. 1998b. Morphological classification of nuchal skin in human fetuses with trisomy 21, 18, and 13 at 12–18 weeks and in a trisomy 16 mouse. *Anat Embryol* **197** (2): 105–124.

von Kaisenberg CS, Nicolaides KH, Brand-Saberi B. 1999. Lymphatic vessel hypoplasia in fetuses with Turner syndrome. *Hum Reprod* **14** (3): 823–826.

Wald NJ, Watt HC, Hackshaw AK. 1999. Integrated screening for Down syndrome on the basis of tests performed during the first and second trimesters. *N Engl J Med* **341** (7): 461–467.

Whitlow BJ, Chatzipapas IK, Economides DL. 1998. The effect of fetal neck position on nuchal translucency measurement. *Br J Obstet Gynaecol* **105** (8): 872–876.

Zosmer N, Souter VL, Chan CSY, Huggon IC, Nicolaides KH. 1999. Early diagnosis of major cardiac defects in chromosomally normal fetuses with increased nuchal translucency. *Br J Obstet Gynaecol* **106** (8): 829–833.

Copyright © 2002 John Wiley & Sons, Ltd.