Clinical utility of non-invasive prenatal testing in pregnancies with ultrasound anomalies

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KEYWORDS: clinical utility; cohort study; etiology; genetic testing; non-invasive prenatal testing; prenatal diagnostic testing; ultrasound anomalies

ABSTRACT

Objective To evaluate the application of non-invasive prenatal testing (NIPT) as an alternative to invasive diagnostic prenatal testing in pregnancies with abnormal ultrasound findings.

Methods This was a retrospective analysis of 251 singleton and multiple pregnancies at high risk for fetal chromosomal abnormality based on findings at sonographic examination, in which NIPT was performed as a first-tier genetic test. NIPT was performed by massively parallel sequencing of cell-free DNA in maternal plasma, allowing genome-wide detection of whole-chromosome, as well as partial, autosomal aneuploidy. Sex chromosomes were not analyzed, according to the current protocol in Dutch laboratories.

Results NIPT was performed at a median gestational age of 20 weeks, indicated by the presence of multiple congenital anomalies (n = 13), isolated structural anomalies (n = 57), increased nuchal translucency ≥ 3.5 mm (n = 58), soft markers (n = 73), growth restriction (n = 40) and other anomalies (n = 10). NIPT results were normal in 224 (89.2%) pregnancies, inconclusive in one (0.4%) and abnormal in 26 (10.4%). Most genetic aberrations detected by NIPT were common whole-chromosome aneuploides: trisomy 21 (n = 13), trisomy 18 (n = 6) and trisomy 13 (n = 3). Four further NIPT results were abnormal; one was suspected of being confined placental mosaicism and one was of maternal origin. In those with normal NIPT results, sonographic follow-up or examination of the newborn indicated the need for diagnostic genetic testing in 33/224 (14.7%) pregnancies. Clinically relevant genetic aberrations were revealed in 7/224 (3.1%) cases, two of which were whole-chromosome aneuploides: trisomy 13 and monosomy X. As sex chromosomal aberrations are not included in NIPT analysis, the latter cannot be considered a false-negative result. Other discordant findings were subchromosomal aberrations (< 20 megabases, n = 2) and monogenic aberrations (n = 3).

Conclusions NIPT should not be recommended for genetic evaluation of the etiology of ultrasound anomalies, as both resolution and sensitivity, or negative predictive value, are inferior to those of conventional karyotyping and microarray analysis. Nonetheless, some pregnant women consider NIPT to be an acceptable alternative to invasive diagnostic testing. © 2016 The Authors. Ultrasound in Obstetrics & Gynecology published by John Wiley & Sons Ltd on behalf of the International Society of Ultrasound in Obstetrics and Gynecology.

INTRODUCTION

Pregnant women at high risk for fetal chromosomal abnormality based on findings at sonographic examination are offered prenatal genetic testing. Genetic evaluation enables determination of the etiology of the ultrasound anomaly, overall fetal prognosis and risk of recurrence in future pregnancies. The information obtained could facilitate prospective parents’ reproductive decision-making when confronted with the choice between terminating pregnancy or continuing pregnancy and preparing themselves for the birth of a child with a physical and/or intellectual disability.

In cases with ultrasound anomalies, fetal genotyping is usually performed by quantitative fluorescent polymerase chain reaction (QF-PCR) of fetal DNA for rapid diagnosis of (an)euploidy of chromosomes 13, 18, 21 and the sex chromosomes. If QF-PCR results are normal, microscopic G-band karyotyping has long been the standard approach to detect chromosomal aberrations at a resolution...
of 5–10 megabases (Mb). At present, chromosomal microarray analysis is recommended instead of, or as an adjunct to, conventional karyotyping, as it allows genome-wide analysis at a much higher resolution (up to 1 kilobase (kb)), revealing clinically significant unbalanced submicroscopic aberrations1–3. However, these techniques all require fetal tissue obtained by an invasive diagnostic procedure, i.e. chorionic villus sampling or amniocentesis. For a considerable number of pregnant women at high risk for fetal chromosomal abnormality, the associated procedure-related risk of miscarriage is a reason to decline invasive diagnostic testing.

The development of non-invasive prenatal testing (NIPT) by massively parallel sequencing (MPS) of cell-free DNA in maternal plasma provides an alternative for the detection of fetal genetic aberrations with the increased safety of performing maternal blood sampling instead of an invasive diagnostic procedure. NIPT detects common whole-chromosome aneuploidy such as trisomy 21 (T21, Down syndrome), trisomy 18 (T18, Edwards syndrome) and trisomy 13 (T13, Patau syndrome) with high sensitivity and specificity4. The non-invasive detection of subchromosomal copy-number variants (CNVs), i.e. microdeletions and microduplications, at a resolution comparable with that of microarray analysis has been shown to be feasible5. However, routine implementation of the latter technique is hampered by its requirements for significantly deeper sequencing, which is costly6. Furthermore, extensive validation is needed to determine accurately its detection rate and false-positive rate, which is difficult owing to the low prevalence of specific genetic aberrations. Nonetheless, some pregnant women at high risk for fetal chromosomal abnormality based on findings at sonographic examination already consider NIPT an acceptable alternative to invasive diagnostic testing.

This study aimed to evaluate the application of NIPT as an alternative to invasive diagnostic testing for the detection of fetal genetic aberrations in pregnancies with ultrasound anomalies.

METHODS

Study design and subjects

This was a retrospective study of all pregnant women at high risk for fetal chromosomal abnormality based on findings at sonographic examination, who underwent NIPT as an alternative to fetal genotyping by QF-PCR and microarray analysis at prenatal diagnostic centers linked to the Network for Prenatal Diagnosis Nijmegen, between April 2014 and November 2015. Ethical approval was granted by the medical ethics committee of the Radboud University Medical Center, Nijmegen, The Netherlands.

Counseling

Pregnant women at high risk for fetal chromosomal abnormality based on sonographic examination were offered prenatal genetic testing. As part of the standard care offered in the prenatal diagnostic centers linked to the Network for Prenatal Diagnosis Nijmegen, all prospective parents included in the cohort received thorough pretest counseling on the test characteristics and potential benefits and disadvantages of different modalities for prenatal genetic testing. Invasive diagnostic testing was offered as the first-tier genetic test, utilizing both QF-PCR and chromosomal microarray analysis, thereby providing maximum information and a definitive diagnosis. Counseling included information on the invasive diagnostic procedure needed to obtain fetal tissue and the associated procedure-related risk of miscarriage, i.e. 0.5% for chorionic villus sampling and 0.3% for amniocentesis.

Counseling on NIPT included information on the test being validated for the detection of only T21, T18 and T13, thus offering limited information compared with invasive diagnostic testing. Pregnant women and their partners were informed that other potentially clinically relevant abnormal test results besides T21, T18 and T13 would be discussed with them. Furthermore, all abnormal test results would have to be confirmed by invasive diagnostic testing, especially when the results would influence management of their pregnancy. Those who decided to have NIPT as an alternative to fetal genotyping by QF-PCR and microarray analysis provided written informed consent for the application of NIPT as a first-tier genetic test.

Genetic testing

For NIPT, maternal blood samples were obtained at one of five diagnostic centers linked to the Network for Prenatal Diagnosis Nijmegen. All samples were then processed and analyzed at the Department of Human Genetics of the Radboud University Medical Center in Nijmegen, as described previously7,8. Briefly, samples underwent centrifugation for plasma separation, followed by manual extraction and MPS of cell-free DNA from maternal plasma. MPS entailed either single-end 50-bp sequencing on a SOLiD 5500 XL Genetic Analyzer (Life Technologies, Foster City, CA, USA) or single-end 75-bp sequencing on a NextSeq 500 desktop sequencer (Illumina, San Diego, CA, USA). After sequencing, reads were mapped to the hg19 reference genome. Samples were tested for fetal chromosomal aberrations using WISECONDOR, a within-sample comparison algorithm using GC-corrected 1-Mb genomic bins9,10. With this algorithm, both whole-chromosome, as well as partial, aneuploidy can be detected. A whole-chromosome fetal trisomy or monosomy is considered detected when at least 50% of the bins of a chromosome are aberrant. Using low sequence coverage (0.1–0.5×), aberrations smaller than 20 Mb cannot be detected reliably owing to natural fluctuations of read-depth frequencies along the genome. Smaller aberrations are, therefore, considered only if visual inspection of the plots strongly suggests a fetal genetic aberration. Currently, in Dutch laboratories, fetal gender and sex chromosomal aberrations are not analyzed when performing NIPT. Furthermore, fetal fraction is
not determined. Instead, it is assumed that the blood
sample contains sufficient cell-free fetal DNA to allow the
identification of fetal chromosomal aberrations.

If prenatal or postnatal diagnostic testing was per-
formed, QF-PCR analysis was carried out according
to standard procedures. In cases of normal QF-PCR
results, genome-wide high-resolution microarray ana-
lysis was carried out according to the manufacturer’s
specifications on an Affymetrix CytoScan HD array plat-
form (Affymetrix, Inc., Santa Clara, CA, USA). Cut-offs
defining abnormal microarray results. If CNVs were inherited from a healthy
father, parents without physical or neurodevelop-
mental anomalies, they were classified as most probably
benign. Targeted DNA testing for monogenic diseases was
analyzed to facilitate the interpretation of abnormal
results of any diagnostic genetic testing and pregnancy
findings of any follow-up sonographic examination.
Pathogenic aberrations detected by genetic testing were
classified as causative findings, unexpected diagnoses
or susceptibility loci for neurodevelopmental disorders
based on their relationship with findings of the
sonographic and/or newborn examination. Aberrations
found unintentionally in prospective parents were
classified as incidental findings12.

RESULTS

Between April 2014 and November 2015, prenatal genetic
testing was performed in 590 pregnant women at high risk
for fetal chromosomal abnormality based on sonographic
examination. NIPT was applied as the first-tier test for
the detection of genetic aberrations in 251 (42.5%) pregnancies. Of these, 230 (91.6%)
were singleton and 21 (8.4%) were multiple pregnancies. In all multiple
pregnancies, ultrasound anomalies were present in only
one of the fetuses when genetic testing was first indicated,
thus also when NIPT was performed. Characteristics of
the pregnant women included in the cohort are shown in
Table 1.

An overview of the findings from NIPT and diagnostic
genetic testing in pregnancies with sonographic anomalies
is shown in Figure 1, Tables 2–4, Table S1 and (showing
multiple gestations only) Table S2. NIPT results were
normal in 224 (89.2%) pregnancies, inconclusive in one
(0.4%) and abnormal in 26 (10.4%).

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>31 (17–44)</td>
</tr>
<tr>
<td>Maternal weight at NIPT (kg)</td>
<td>69 (44–123)</td>
</tr>
<tr>
<td>Singleton pregnancy</td>
<td>230 (91.6)</td>
</tr>
<tr>
<td>Multiple pregnancy</td>
<td>21 (8.4)</td>
</tr>
<tr>
<td>Primigravid</td>
<td>94 (37.3)</td>
</tr>
<tr>
<td>Multigravid</td>
<td>157 (62.5)</td>
</tr>
<tr>
<td>Nulliparous</td>
<td>119 (47.4)</td>
</tr>
<tr>
<td>Parous</td>
<td>132 (52.6)</td>
</tr>
<tr>
<td>GA at NIPT (weeks)*</td>
<td>20 (10–34)</td>
</tr>
</tbody>
</table>

Data are given as median (range) or n (%). *Gestational age (GA)
had bimodal distribution, with peaks at 12–13 weeks and at
20–21 weeks.

Abnormal NIPT result

The majority of genetic aberrations detected by NIPT
were whole-chromosome aneuploidies: 13 cases of T21,
six cases of T18, three cases of T13 and one case of trisomy
16. Follow-up diagnostic genetic testing was performed in 21 of these 23 pregnancies.

In two cases, the findings of NIPT and diagnostic
genetic testing were discordant. In one specific case,
prenatal testing was indicated for genetic evaluation of
the etiology of multiple structural anomalies present in
one fetus of a dichorionic twin pregnancy. No structural
anomaly was observed in the other fetus when NIPT
was performed at 12+5 weeks' gestation. NIPT was
abnormal, indicating the presence of T21. Follow-up
sonographic examination at 17 weeks' gestation revealed
an atrioventricular septal defect and absent nasal bone,
suggestive of T21, in the fetus without previously detected
anomalies. QF-PCR analysis of fetal tissue obtained by
amniocentesis confirmed the presence of T21 (detected
by NIPT) in this fetus, but also detected T13 (not
detected by NIPT) in the other fetus. When NIPT was
repeated for research purposes at 17+5 weeks' gestation,
both aneuploidies were detected. The pregnancy was
terminated.

In the second case with discordant results, NIPT
revealed fetal trisomy 16, or mosaic thereof, which could
be confirmed neither by karyotyping of amniotic fluid
nor by fluorescent in-situ hybridization analysis using a
probe specific for chromosome 16 (D16Z3). However,
postnatal microarray analysis revealed the presence of
maternal uniparental disomy of chromosome 16, most
probably owing to so-called ‘trisomy 16 rescue’. This,
in combination with the observed intrauterine growth
restriction and preterm birth, led to a suspected diagnosis
of confined placental mosaicism. Unfortunately, placental
material was not available for testing (Table 2).

In two cases, abnormal NIPT results were not
confirmed by diagnostic genetic testing. In one case, a
dichorionic twin pregnancy, prenatal testing was indicated
because of a high risk for fetal aneuploidy based on
prenatal screening by first-trimester combined test

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NIPT abnormal (n = 26)

Follow-up diagnostic genetic testing:
3 T13
5 T18
11 T21
1 T21 and T13 (NIPT indicated T21) (Case 2)
1 UPD(16)mat (NIPT indicated T16) (Case 3)
1 dup 8p23.1p11.21 ~29 Mb and del 8p23.3p23.1 ~6.8 Mb (Case 4)
1 maternal dup 21q22.11 ~370 kb (Case 5)

NIPT inconclusive (n = 1; Case 1)

Aberrations detected by diagnostic genetic testing (n = 12):
Chromosomal aberrations (n = 9):
1 T13 (Case 7)
1 45,X (Case 8)
1 del 14q32.2q32.33 ~3.9 Mb (Case 9)
1 del 4p16.3p15.33 ~14.8 Mb (Wolf–Hirschhorn syndrome) and
dup 10q26.11q26.13 ~15.3 Mb (Case 10)
5 parentally inherited CNVs < 1 Mb
Monogenic aberrations (n = 3):
1 homozygous mutation in KCNQ1OT1 gene (MOPD1) (Case 11)
1 hypomethylation in KCNQ1OT1 gene (LIT1) (Beckwith–Wiedemann syndrome) and gain 16p11.2 ~610 kb (susceptibility locus) (Case 12)
1 homozygous mutation in CFTR gene (delta F508) (cystic fibrosis) (Case 13)

NIPT normal (n = 224)

No aberrations detected (n = 212):
No diagnostic genetic testing indicated (n = 191)
Diagnostic genetic testing normal (n = 21)

Figure 1 Flowchart of results of non-invasive prenatal testing (NIPT) in 251 pregnancies with ultrasound anomaly. NIPT was by massively parallel sequencing of cell-free DNA in maternal plasma. Diagnostic genetic testing was by quantitative fluorescent polymerase chain reaction, karyotyping, microarray analysis or targeted DNA testing of fetal or maternal tissue. Case 1: genetic testing indicated by polyhydramnios, NIPT did not meet quality criteria, however, visual inspection of plots repeatedly showed suspect chromosome 22 profile. Mother had mild intellectual disability, shortened palate, mild hearing impairment, common variable immunodeficiency. Maternal array was 22q11.21(18,970,562-21,465,660)×1, ~2.5 megabases (Mb). No further genetic testing. Resulted in live birth with no congenital anomaly. Postnatal microarray of newborn revealed 22q11.21(18,648,867-21,798,908)×1 mat, ~2.8 Mb. Case 2: multiple pregnancy, genetic testing indicated by multiple structural anomalies (intrauterine growth restriction, holoprosencephaly, omphalocele, megacystis with bilateral hydro-nephrosis) in one fetus. No structural anomaly was observed in other fetus. NIPT showed T21. Follow-up ultrasound at 17 weeks' gestation revealed atrioventricular septal defect and absent nasal bone in fetus without previously detected anomalies. Amniocentesis and genetic testing showed 47,XY + 21 and 47,XY + 13. Pregnancy was terminated. Cases 3–13 summarized in Tables 2 and 3. CNV, copy number variant; del, deletion; dup, duplication; kb, kilobases; MOPD1, microcephaly osteodysplastic primordial dwarfism Type I; T13, trisomy 13 (Patau syndrome); T16, trisomy 16; T18, trisomy 18 (Edwards syndrome); T21, trisomy 21 (Down syndrome); UPD(16)mat, maternal uniparental disomy of chromosome 16.

(risk: T21, 1:6; T18, 1:22; T13, 1:45), with a nuchal translucency thickness of 3.8 mm in one fetus. The risk for fetal aneuploidy in the other fetus was not elevated. NIPT was performed at 12 + 6 weeks' gestation and indicated the presence of T21. Sonographic follow-up diagnosed intrauterine demise of the affected twin at 14 weeks. Amniocentesis was performed only on the fetus with normal nuchal translucency. QF-PCR results were normal.

In the second case with an abnormal NIPT result not confirmed by diagnostic genetic testing, prenatal testing was indicated by the presence of multiple structural anomalies (semilobar holoprosencephaly, atrioventricular septal defect with hypoplastic left heart) and severe intrauterine growth restriction. Although fetal T18, detected by NIPT, fitted the phenotype, consent for prenatal or postnatal diagnostic testing was not given. The pregnancy ended in intrauterine fetal demise.

Subchromosomal aberrations were detected by NIPT in three other pregnancies (Table 2). Owing to the relatively high region-specific Z-score in one case, a maternal origin was suspected, which was subsequently confirmed via microarray analysis of the mother’s genomic DNA. Consultation with a clinical geneticist revealed no maternal dysmorphic features, or physical or neurodevelopmental anomaly, therefore the CNV was classified as most probably benign. In another case, NIPT detected accurately an inverted duplication deletion of chromosome 8p. In the third case, a gain of chromosome 18p was detected, however, consent for prenatal or postnatal diagnostic confirmation was not given. Newborn examination revealed mild dysmorphic features and two small ventricular septal defects that resolved spontaneously.

Normal NIPT result

Among the 224 pregnancies with normal NIPT results, (additional) findings at sonographic follow-up or newborn examination indicated the need for diagnostic genetic
Table 2 Overview of cases with abnormal non-invasive prenatal test (NIPT) result other than trisomy 21, 18 or 13, in 251 pregnancies with ultrasound anomaly

<table>
<thead>
<tr>
<th>Case</th>
<th>Indication for genetic testing</th>
<th>NIPT</th>
<th>Diagnostic genetic testing</th>
<th>Outcome</th>
<th>Classification of aberration</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Timing</td>
<td>Test</td>
<td>Result</td>
<td>Timing</td>
</tr>
<tr>
<td>3</td>
<td>IUGR</td>
<td>15 weeks</td>
<td>T16</td>
<td>QF-PCR, karyotype, FISH</td>
<td>16 weeks</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Postnatal Microarray</td>
<td>arr 16p13.3p13, 2 (89,561-8,914,906) × 2 hmz = UPD (16)(mat∗)</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>NT 4.7 mm</td>
<td>13 weeks</td>
<td>Gain of 8p†</td>
<td>16 weeks</td>
<td>Karyotype, microarray</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>arr 8p23.3p23.1(158, 049-6,976,182) × 1 dn, 6.8 Mb, 8p23.1p11.21</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>IUGR</td>
<td>21 weeks</td>
<td>Gain of 21q‡</td>
<td>22 weeks</td>
<td>Maternal microarray</td>
</tr>
<tr>
<td>6</td>
<td>IUGR</td>
<td>21 weeks</td>
<td>Gain of 18p§</td>
<td>NP</td>
<td></td>
</tr>
</tbody>
</table>

*Maternal uniparental disomy of chromosome 16, most likely due to ‘trisomy 16 rescue’; placental material not available for testing. †Software analysis showed 30-Mb gain of 8p; visual inspection of plots showed also a (smaller) 8p terminal loss. ‡Software analysis showed 10-Mb gain of 21q; visual inspection of plots showed relatively high region-specific Z-score, therefore, maternal origin was suspected; consultation with clinical geneticist revealed no maternal dysmorphic features or physical or neurodevelopmental anomaly; copy number variant therefore classified as most probably benign. §Software analysis showed 15-Mb gain of 18p. FISH, fluorescent in-situ hybridization; IUGR, intrauterine growth restriction; kb, kilobases; LB, live birth; Mb, megabases; NP, not performed; NT, nuchal translucency thickness; QF-PCR, quantitative fluorescent polymerase chain reaction; T16, trisomy 16; TOP, termination of pregnancy; VSD, ventricular septal defect.

Testing in 33 (14.7%) cases. Diagnostic testing revealed genetic aberrations in 12 of these pregnancies, seven (3.1%) of which were clinically relevant (Table 3). In all other cases, newborn examination was normal or showed congenital anomalies that did not indicate the need for additional genetic testing.

Aside from the previously described case of a diamniotic twin pregnancy with an abnormal NIPT result indicating T21 but missing T13, NIPT did not detect two other common whole-chromosome aneuploidies: one case of T13 and one of monosomy X. As sex chromosomal aberrations were not included in the NIPT analysis, the latter aneuploidy cannot be considered a false-negative result. In two other cases, clinically relevant subchromosomal aberrations were not detected by NIPT: ~14.8-Mb 4p16.3p15.33 deletion, associated with Wolf–Hirschhorn syndrome, in combination with ~15.3-Mb 10q26.11q26.3 duplication in one case, and a submicroscopic ~3.9-Mb 14q32.2q32.33 deletion in another case. Other subchromosomal aberrations detected by postnatal diagnostic testing were parentally inherited CNVs of <1 Mb. As all were inherited from a healthy parent, these were classified as most probably benign and not clinically relevant. Targeted DNA testing confirmed the presence of monogenic aberrations in three other cases. These monogenic aberrations cannot be detected by techniques based on whole-genome analysis of CNVs, such as NIPT or microarray analysis.

If invasive diagnostic testing with QF-PCR and chromosomal microarray analysis had been performed as the first-tier genetic test in all pregnancies included in the cohort, genetic aberrations would have been detected in 12.7% instead of 10.4% of all pregnancies, excluding parentally inherited CNVs <1 Mb as these were most probably benign and not clinically relevant (Table 4).

**DISCUSSION**

Our study evaluates the application of NIPT for prenatal genetic testing in pregnancies at high risk for fetal chromosomal abnormality based on findings at sonographic examination. Our findings show that NIPT should not be recommended as an alternative to invasive diagnostic testing for genetic evaluation of the etiology of ultrasound anomalies. Both resolution and sensitivity, or negative predictive value, are inferior to those of the diagnostic genetic test modalities currently available.
### Table 3
Overview of cases with clinically relevant aberration revealed by diagnostic genetic testing after normal non-invasive prenatal test (NIPT) result in 251 pregnancies with ultrasound (US) anomaly

<table>
<thead>
<tr>
<th>Case</th>
<th>Indication for genetic testing</th>
<th>Timing</th>
<th>Diagnostic genetic testing</th>
<th>Result</th>
<th>Outcome</th>
<th>Classification of aberration</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>MCA</td>
<td>14 weeks</td>
<td>17 weeks QF-PCR</td>
<td>47,XY + 13</td>
<td>IUFD (US at 17 weeks)</td>
<td>Causative</td>
</tr>
<tr>
<td>8</td>
<td>Hydrops fetalis</td>
<td>12 weeks</td>
<td>Postnatal QF-PCR</td>
<td>45,X</td>
<td>IUFD (US at 18 weeks)</td>
<td>Causative</td>
</tr>
<tr>
<td>9</td>
<td>NT 3.9 mm</td>
<td>21 weeks</td>
<td>32 weeks Microarray</td>
<td>14q32.2q32.33(101,220,548-105,080,719) × 1 dn, 3.9 Mb</td>
<td>Unilateral hydrothorax (US at 32 weeks), anal atresia, some mild dysmorphisms</td>
<td>Causative</td>
</tr>
<tr>
<td>10</td>
<td>IUGR</td>
<td>23 weeks</td>
<td>Postnatal Microarray</td>
<td>4p16.3p15.33(68,346-14,875,532) × 1 dn, 14.8 Mb (Wolf–Hirschhorn syndrome) 10q26.11q26.3(120,145,796-135,427,144) × 3 dn, 15.3 Mb</td>
<td>Severe dysmaturity, microcephaly, some dysmorphisms</td>
<td>Causative</td>
</tr>
<tr>
<td>11</td>
<td>MCA</td>
<td>30 weeks</td>
<td>Postnatal DNA</td>
<td>Homozygous pathogenic mutation in RNU4ATAC gene (LIT1) (MOPD1)</td>
<td>Severe dysmaturity, microcephaly, severe intracerebral abnormalities, VSD, several dysmorphisms, bilateral rocker bottom feet</td>
<td>Causative</td>
</tr>
<tr>
<td>12</td>
<td>Omphalocele</td>
<td>14 weeks</td>
<td>Postnatal Microarray</td>
<td>16p11.2(29,567,296-30,178,000) × 3 dn, 610 kb (susceptibility locus) DNA hypomethylation in KCNQ1OT1 gene (Beckwith–Wiedemann syndrome)</td>
<td>Omphalocele, unilateral duplex collecting system and ureterocele (US at 18 weeks), earlobe creases</td>
<td>Susceptibility locus; causative</td>
</tr>
<tr>
<td>13</td>
<td>Echogenic bowel</td>
<td>21 weeks</td>
<td>23 weeks* DNA</td>
<td>Homozygous pathogenic mutation in CFTR gene (deltaF508) (cystic fibrosis)</td>
<td>TOP</td>
<td>Causative</td>
</tr>
</tbody>
</table>

*Parental carrier screening confirmed presence of maternal and paternal pathogenic mutations in CFTR gene (deltaF508). IUFD, intrauterine fetal demise; IUGR, intrauterine growth restriction; kb, kilobases; Mb, megabases; MCA, multiple congenital anomalies; MOPD1, microcephaly osteodysplastic primordial dwarfism Type I; NT, nuchal translucency thickness; QF-PCR, quantitative fluorescent polymerase chain reaction; TOP, termination of pregnancy; VSD, ventricular septal defect.

i.e. conventional G-band karyotyping and chromosomal microarray analysis.

NIPT for the detection of fetal genetic aberrations in pregnancies with ultrasound anomalies yielded 10.4% abnormal results. This is considerably higher than the yield found in pregnancies at high risk for fetal chromosomal abnormality based on a personal or family history of chromosomal abnormality or prenatal screening by first-trimester combined testing (5.2% abnormal NIPT results in the same timeframe, applying the same laboratory protocol; own unpublished data). This is in accordance with the high prevalence of fetal genetic aberrations in the population studied. Chromosomal and subchromosomal genetic aberrations that can be detected by conventional karyotyping are present in 9–19% of fetuses with single and multiple anomalies, respectively. Clinically relevant submicroscopic CNVs detected by microarray analysis are found in 5–10% of fetuses with ultrasound anomalies and a normal karyotype.

With the present state of technology, NIPT should be able to detect common whole-chromosome aneuploidies with high sensitivity and specificity. However, in this study population, two out of five cases of T13 were not detected by NIPT. Discordant findings could possibly be explained by a low fraction of fetal DNA within these samples, directly affecting the diagnostic
In conclusion, NIPT should not be recommended for the test, the intention to terminate or continue pregnancy in case of (relevant) fetal genetic aberrations, and acceptability of the risk of a procedure-related miscarriage. Therefore, the choice of a prenatal test should be theirs to make, provided they receive thorough pretest counseling on the characteristics of genetic tests currently available. Pregnant women and their partners should be made fully aware that the information provided by NIPT is inferior to the information provided by invasive diagnostic testing. Furthermore, pregnant women should realize that there is a chance of unlooked-for findings in the form of maternal CNVs.

For pregnancies included in this study, fear of a procedure-related miscarriage and unwillingness to terminate the pregnancy in case of fetal chromosomal abnormality were often noted as reasons for declining invasive diagnostic testing. Unfortunately, the data extracted from medical records were insufficient for further analysis of prospective parents’ decision-making. Prospective studies comparing the utility of invasive diagnostic testing with the utility of NIPT for genetic evaluation of pregnancies with ultrasound anomalies should be performed to enable further analysis of prospective parents’ decision-making regarding prenatal genetic testing, e.g., preferences, reasons for choosing a certain test modality, informed decision-making, decisional conflict and decision regret.

This study is limited by the fact that, although complete follow-up of pregnancy outcomes was ascertained, diagnostic genetic testing was not performed when sonography or newborn examination did not call for it. In conclusion, NIPT should not be recommended for genetic evaluation of the etiology of ultrasound anomalies, as both resolution and sensitivity, or negative predictive value, are inferior to those of conventional karyotyping and microarray analysis. Nonetheless, some pregnant women consider NIPT to be an acceptable alternative to invasive diagnostic testing.

ACKNOWLEDGMENTS

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