Diagnostic quality of 3Tesla postmortem magnetic resonance imaging in fetuses with and without congenital heart disease

Barbara Ulm, MD; Gregor O. Dovjak, MD, PhD; Anke Scharrer, MD; Dana A. Muin, MD, MSc; Daniel Zimpfer, MD; Daniela Prayer, MD; Michael Weber, PhD; Vanessa Berger-Kulemann, MD

BACKGROUND: Postmortem confirmation of prenatally diagnosed congenital heart disease after termination of pregnancy and evaluation of potential cardiac defects after spontaneous fetal or neonatal death are essential. Conventional autopsy rates are decreasing, and 1.5Tesla magnetic resonance imaging has demonstrated limited diagnostic accuracy for postmortem cardiovascular assessment.

OBJECTIVE: This study aimed to evaluate the feasibility and image quality of cardiac 3Tesla postmortem magnetic resonance imaging and to assess its diagnostic accuracy in detecting fetal heart defects compared with conventional autopsy. Secondly, the study aimed to explore whether clinical factors affect the quality of 3Tesla postmortem magnetic resonance imaging.

STUDY DESIGN: A total of 222 consecutive fetuses between 12 and 41 weeks’ gestation, who underwent 3Tesla postmortem magnetic resonance imaging and conventional autopsy after spontaneous death or termination of pregnancy for fetal malformations, were included. First, 3Tesla postmortem magnetic resonance imaging of each fetus was rated as diagnostic or nondiagnostic for fetal cardiac assessment by 2 independent raters. The image quality of individual cardiac structures was then further evaluated by visual grading analysis. Finally, the presence or absence of a congenital heart defect was assessed by 2 radiologists and compared with autopsy results.

RESULTS: Overall, 87.8% of 3Tesla postmortem magnetic resonance imaging examinations were rated as diagnostic for the fetal heart. Diagnostic imaging rates of individual cardiac structures at 3Tesla postmortem magnetic resonance imaging ranged from 85.1% (atrioventricular valves) to 94.6% (pericardium), with an interrater agreement of 0.82 (0.78–0.86). Diagnostic imaging of the fetal aortic arch and the systemic veins at 3Tesla postmortem magnetic resonance imaging was possible from 12+5 weeks’ gestation onward in 90.1% and 92.3% of cases, respectively. A total of 55 fetuses (24.8%) had at least 1 cardiac anomaly according to autopsy, 164 (73.9%) had a normal heart, and in 3 fetuses (1.4%), autopsy was nondiagnostic for the heart. Considering all examinations rated as diagnostic, 3Tesla postmortem magnetic resonance imaging provided high diagnostic accuracy for the detection of fetal congenital heart defects with a sensitivity of 87.8%, a specificity of 97.9%, and concordance with autopsy of 95.3%. 3Tesla postmortem magnetic resonance imaging was less accurate in young fetuses (<20 weeks compared with >20 weeks; P<.001), in fetuses with low birthweight (<100 g compared with >100 g; P<.001), in cases after spontaneous fetal death (compared with other modes of death; P=.012), in cases with increasing latency between death and 3Tesla postmortem magnetic resonance imaging (P<.001), and in cases in which there was a high degree of maceration (maceration score of 3 compared with a score from 0 to 2; P=.004).

CONCLUSION: Diagnostic 3Tesla postmortem magnetic resonance imaging assessment of the fetal heart is feasible in most fetuses from 12 weeks’ gestation onward. In diagnostic images, sensitivity and, particularly, specificity in the detection of congenital heart disease are high compared with conventional autopsy. Owing to its high diagnostic accuracy, we suggest that 3Tesla postmortem magnetic resonance imaging may serve as a suitable imaging modality with which to direct a targeted conventional autopsy when pathology resources are limited or to provide a virtual autopsy when full autopsy is declined by the parents.

Key words: autopsy, coarctation of the aorta, congenital heart disease, fetal heart, hypoplastic left heart, hypoplastic right heart, magnetic resonance imaging, postmortem imaging, prenatal diagnosis, prenatal ultrasound, tetralogy of Fallot, truncus arteriosus

Introduction
Congenital heart disease (CHD) is the most common malformation in fetuses and newborns, with a prevalence of 8 per 1000, comprising live births, fetal deaths after 20 weeks’ gestation, and terminations of pregnancy for fetal malformations.1 In Europe, up to 44% of pregnancies are terminated prematurely owing to prenatally diagnosed CHD, either in isolation or as part of complex syndromes.1,2 Indeed, the diagnostic quality of prenatal screening for CHD varies widely owing to the limited availability of specialists.2,3 Moreover, the diagnostic accuracy of cardiac ultrasound (US) is limited per se, even when performed by specialists.2,4,5 The prenatal diagnosis of CHD has been improved recently by using intelligent methods, such as fetal intelligent navigation echocardiography, with more than 90% diagnostic accuracy, but these techniques are not yet widely used.6 Finally, only a relatively small proportion of fetuses undergo targeted cardiac US for suspicion of CHD. Accordingly, the cause of spontaneous death in utero is often unclear.

A postnatal, full workup of fetal malformations is essential: even if prenatal US suggests CHD, this suspected
Why was this study conducted?
This study aimed to evaluate the feasibility, image quality, and accuracy of cardiac 3T pmMRI in a consecutive series of fetuses for the detection of congenital heart defects compared with autopsy and to explore whether clinical factors affect the quality of postmortem imaging.

Key findings
3T pmMRI was feasible from early gestation onward, and image quality was diagnostic in 87.8% of examinations. Compared with autopsy and after exclusion of nondiagnostic images, the accuracy of 3T pmMRI for the detection of heart defects was high, with a sensitivity of 87.8%, a specificity of 97.9%, and concordance with autopsy results of 95.3%.

What does this add to what is known?
Cardiac 3T pmMRI is feasible for fetal postmortem examination from 12 weeks onward and may act as a decision tool for further investigation or invasive postmortem assessment.

Postmortem magnetic resonance imaging and image analyses
Fetuses were kept in a refrigerator at 4°C from birth until 3T pmMRI. 3T pmMRI examinations were performed outside of routine office hours in order to not disturb clinical routines, within 24 hours after delivery. Acquisition of the 3T pmMRI examination depended mainly on the availability of radiologists and MRI scanners in the evening and during the night; in any case, the corpse was brought to the Department of Pathology for full autopsy after 3T pmMRI within 24 to 48 hours.

All pmMRIs were performed on a 3T scanner (Magnetom Trio and Magnetom...
Vida, Siemens Medical Systems, Erlangen, Germany) using a knee coil, flex coil, or body coil according to the size of the fetus. To date, examination protocols for the body, excluding the brain, have consisted of T2-weighted images (with the field of view [FOV] depending on the region) of the body in at least 2 orthogonal planes (axial and coronal). The sagittal plane and oblique planes were reconstructed from the original data set (3-dimensional [3D] constructive interference in steady state [CISS]), if available. The following acquisition parameters were used (T2, CISS): repetition time [TR], 1000–2500 ms; 6.26–67.04 ms; echo time [TE], 122–157 ms; 2.75–3.17 ms; slice thickness, 0.4–3 mm; 0.4–0.5 mm; flip angle [FA], 100–149; 42–46; voxel size 0.3 × 0.3 × 0.4 mm³; 0.6 × 0.6 × 0.6 mm³; 0.4 × 0.4 × 0.4 mm³; and FOV, 130–140 mm, 157–230 mm (details on 3T pmMRI protocols can be found in Supplementary Materials).

To assess the feasibility and the image quality of fetal cardiac pmMRI and to detect potential cardiac malformations, 2 experienced radiologists (4 years and 11 years of experience in cardiac imaging; 2 years of limited experience in postmortem imaging), who were blinded to any clinical information (US findings, gestational age, mode of death, autopsy results), independently rated different anatomic structures of the fetal heart and the great vessels on a picture archiving and communication system (AGFA). The following structures were evaluated: left and right atria, left and right ventricles, atrial and ventricular septum, atroventricular valves, left and right heart outflow tracts, aortic origin and aortic arch, pulmonary arteries including the ductus arteriosus Botalli, pericardium, pulmonary veins, and venae cavae.

Each cardiac structure was scored independently, receiving a score of 1 if the anatomic structure was clearly visible and assessable without restriction (regardless of normal or abnormal); a score of 2 if visibility was limited, but assessable with restriction; and a score of 3 if the structure was not clearly visible and not assessable (nondiagnostic).

Interrater agreement and Cohen’s kappa values were calculated from the individual scoring results of the 2 independent raters (step 1). Cardiac structures were grouped together when the specific ratings of 1 structure (such as the mitral valve) were always identical with the ratings of the anatomically similar or corresponding structure (such as the tricuspid valve). Only cardiac structures that were visible simultaneously, provided that the correct axes could be displayed, were grouped together. In cases where the 2 raters scored the visibility of cardiac anatomic structures as diagnostic, but at different levels, consensus was then obtained in a second scoring round and a final score was calculated (step 2). Nondiagnostic images (score 3 on our scale) were noted when 1 or both raters considered that the respective cardiac structures were not assessable enough to be rated as diagnostic (no consensus required). When a CHD was noted, the specific suggested cardiac malformation diagnoses, based on 3T pmMRI, were noted in agreement between the 2 radiologists (1 with less and 1 with more experience in cardiac imaging; step 3).

Pathology
A senior fetal pathologist performed the autopsy in all cases according to a pre-designed protocol (Supplementary Material: Protocol for fetal and perinatal autopsies). Only when all personnel involved in patient care agreed that there was no scientific or legal reason for autopsy and no relevant information regarding the cause and circumstances of death was to be expected from invasive postmortem examination, the parents were given the choice to forego autopsy. Autopsy reports were reviewed by a pathologist blinded to US and pmMRI records, but aware of the maternal obstetrical history, gestational age, and mode of fetal death.

The primary endpoints of analyses were the feasibility and the image quality of 3T pmMRI for the depiction of individual fetal cardiac structures. Feasibility was based on binary discrimination of diagnostic vs nondiagnostic examinations of individual cardiac structures at 3T pmMRI. Image quality was assessed using a 3-stage visual grading scale and rated very good to good, moderate but diagnostic, and nondiagnostic imaging of individual cardiac structures at 3T pmMRI.

Secondary aims were to assess diagnostic accuracy of 3T pmMRI in the detection of fetal CHD compared with autopsy and, furthermore, to evaluate the clinical factors that could affect the rate of diagnostic examinations at 3T pmMRI and concordance with autopsy results. Concordance with autopsy results was recorded when both 3T pmMRI and autopsy agreed about the presence or absence of a fetal or neonatal CHD, without further consideration of whether the specific CHD had been diagnosed correctly at 3T pmMRI. Clinical factors assessed for their influence on feasibility and concordance rates were gestational age, birthweight, the reason for fetal or neonatal death (if known), and the circumstances of death (pharmaceutical TOP with and without feticide or spontaneous death; live birth vs stillbirth), the presence or absence of extracardiac malformations, and time between death and 3T pmMRI.

We intentionally did not compare the diagnostic quality of 3T pmMRI vs prenatal US, because this was not the primary aim of our study, and fetal echocardiography reports were inconsistent and oftentimes from substantially earlier gestational ages than fetal death, 3T pmMRI, and autopsy.

Statistical analysis
Statistical analyses were performed using IBM SPSS Statistics for Windows version 26.8 (IBM Corp, Armonk, NY). Categorical data are presented as absolute frequencies and percentages. Comparisons between groups were calculated using chi-square tests. For diagnostic quality measures (sensitivity, specificity, negative and positive predictive value, and accuracy), nondiagnostic cases were treated as either wrong diagnoses (version A) or excluded (version B). In addition, 95% confidence intervals (CIs) according to Wilson (for smaller n) were assessed. To compare quality measures obtained for...
versions A and B, general estimation equations models were used. Rater agreement was measured by calculating the percentage of identical ratings as by Cohen’s kappa. $P\leq0.05$ was considered to indicate significant results.

### Results

#### Demographics

Our initial data set consisted of 262 consecutive fetal 3T pmMRIs from 2012 to 2019. A total of 40 fetuses (40 of 262, 15.3%) were excluded owing to missing prenatal US reports (14), missing whole-body sequences in 3T pmMRI (15), or unavailable autopsy reports (11). The data from 222 fetuses were included, of which 55 (55 of 222, 24.8%) had 1 or several structural heart defects and 164 (164 of 222, 73.9%) had a normal heart according to autopsy. The characteristics of fetuses included are summarized in Table 1.

Of 222 fetal 3T pmMRIs, 115 (51.8%) were 3D, allowing for reconstruction of sagittal and oblique planes (3D CISS), whereas 107 3T pmMRI examinations (48.2%) were in only 2 orthogonal planes.

### Feasibility of cardiac 3Tesla postmortem magnetic resonance imaging and diagnostic examination rates for individual cardiac structures

Diagnostic examination rates for fetal cardiac structures in 3T pmMRI (Figure 1 A) with rater agreements are provided in Table 2. A complete depiction of the 4-chamber view (both atria, atrioventricular valves, ventricles, atrial and ventricular septum) and the outflow tracts (left and right including both ventriculoarterial valves) was feasible in 83.8% (4-chamber view) and 88.3% (outflow tracts) of 3T pmMRI examinations, when autopsy was diagnostic.

Diagnostic rating of the aortic arch (90.1%) and the systemic veins (92.3%) was successful from 12+5 gestational weeks (earliest case studied) onward. After 16 gestational weeks, depiction of the complete 4-chamber view (90.1%), the outflow tracts (93.2%), the aortic arch (93.2%), and the systemic veins (95.5%) was possible in at least 90% of fetuses. Rater agreements between radiologists for individual cardiac structures as either diagnostic (rating scores of 1 or 2) or nondiagnostic (rating score of 3) were 96.8%, on average (94.6% to 98.2%). Overall interrater agreement about diagnostic (scores of 1 and 2) vs nondiagnostic (score of 3) imaging of individual cardiac structures (Cohen’s kappa) was 0.82 (95% CI, 0.78–0.86).

#### Diagnostic accuracy of cardiac 3Tesla postmortem magnetic resonance imaging to detect congenital heart disease, compared with conventional autopsy

The overall sensitivity of 3T pmMRI in diagnosing fetal CHD was 78.2% (43 of 55; 95% CI, 0.656–0.871), with a specificity of 85.4% (140 of 164; 95% CI, 0.791–0.900) and a concordance of 83.6% (183 of 219; 95% CI, 0.781–0.879). Concordance rates of cardiac 3T pmMRI (Figure 1, C) and prenatal US compared with autopsy for the diagnosis of fetal CHD are summarized in Table 3. Cardiac 3T pmMRI was significantly less accurate in fetuses below 20 weeks and in fetuses with a birthweight of ≤100 grams compared with pmMRI in fetuses at ≥20 weeks ($P<0.001$) and fetuses >100 g ($P<0.001$). The presence of extracardiac, intrathoracic abnormalities was associated with decreased 3T pmMRI diagnostic accuracy ($P=0.079$).

Concordance rates between 3T pmMRI and conventional autopsy were significantly lower after spontaneous intrauterine fetal death than other modes of death ($P=0.012$). Stillbirth was associated with lower concordance rates than live birth ($136$ of $170$ vs $47$ of $52$; $P=0.098$). Increasing time intervals between death and 3T pmMRI decreased concordance rates progressively ($P<0.001$). Third-degree maceration was associated with lower concordance rates than maceration scores of 0 to 2 ($P=0.004$).

Diagnostic accuracy was based on the data from 219 fetuses in which conventional autopsy reports were diagnostic. Nondiagnostic ratings from cardiac 3T pmMRI were considered false negative. We also assessed the diagnostic accuracy (n=192; pmMRI) when nondiagnostic ratings were excluded from calculation. Diagnostic accuracy data for both

### Table 1

| Parameters                        | Values                                      |
|----------------------------------|---------------------------------------------|
| Gestational age                  | 22 wk + 2 d (12 wk + 5 d – 41 wk + 0 d)     |
| Fetal/neonatal weight (g)        | 444 (10–3800)                               |
| Male fetus                       | 104 (46.8)                                  |
| Postmortem interval time:        |                                             |
| Death to 3T pmMRI (d)            | 1 (0–112)                                   |
| Death to autopsy (d)             | 3 (1–112)                                   |
| Results of cardiac 3T pmMRI:     |                                             |
| Congenital heart defect(s) present | 47 (21.2)                                   |
| Normal heart                     | 148 (66.7)                                  |
| Nondiagnostic for the fetal heart | 27 (12.2)                                   |
| Autopsy:                         |                                             |
| Congenital heart defect(s) present | 55 (24.8)                                   |
| Normal heart                     | 164 (73.9)                                  |
| Nondiagnostic for the fetal heart | 3 (1.4)                                    |

Values are expressed as median (range) or number (percentages).

3T pmMRI, 3Tesla postmortem magnetic resonance imaging.

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modalities (nondiagnostic cases rated as false-negative vs deleted) are compared in Figure 2. Exclusion of nondiagnostic 3T pmMRI images led to significantly higher diagnostic quality rates, with a sensitivity of 87.8% (43 of 49; P=.01), a specificity of 97.9% (140 of 143; P<.001), and a concordance of 95.3% (183 of 192; P<.001).

The spectrum of cardiac malformations diagnosed on 3T pmMRI and prenatal US are presented in Table 4. Normal fetal cardiac images in 3T pmMRI are displayed in Figures 3 and 4, and postmortem CHDs in fetuses from weeks 14 to 23 are shown in Figure 5. Further cardiac pathologies are detailed in Supplementary Material.

Details of cardiac pathologies are given in Supplemental Table 2, and the reasons for nondiagnostic ratings in 3T pmMRI are summarized in Supplemental Table 3.

Discussion

Principal findings

3T pmMRI is a feasible imaging modality with which to assess the fetal heart and great vessels postmortem. Furthermore, 3T pmMRI provides high diagnostic accuracy for a wide spectrum of cardiac anomalies compared with conventional autopsy. The rate of nondiagnostic images and, subsequently, impaired diagnostic accuracy in the detection of CHD is related to factors, such as low birthweight (below 100 g), extracardiac thoracic anomalies, and advanced maceration.16,17,19

Results

We were able to validate the feasibility of 3T pmMRI of the fetal heart and great vessels regardless of gestational age, in the largest series of 222 consecutive fetuses thus far. Depiction of individual cardiac structures was feasible in more than 9 of 10 fetuses from 16 gestational
### TABLE 2
Diagnostic examination rates, interrater agreement and Cohen’s kappa values of 3Tesla cardiac pmMRI for individual cardiac structures in 222 fetuses

| Fetal cardiac structures                              | Diagnostic examinations at 3T pmMRI | Interrater agreement | Cohen’s kappa (95% confidence interval) |
|--------------------------------------------------------|------------------------------------|----------------------|----------------------------------------|
| Atria (left and right)                                 | 199 (89.6)                         | 97.3                | 0.849 (0.730—0.967)                    |
| Atrioventricular valves (mitral valve, tricuspid valve)| 189 (85.1)                         | 96.8                | 0.863 (0.765—0.962)                    |
| Ventricles (left and right)                            | 200 (90.1)                         | 97.7                | 0.866 (0.750—0.981)                    |
| Atrial and ventricular septum                          | 194 (87.4)                         | 97.3                | 0.865 (0.759—0.971)                    |
| Left ventricular outflow tract, aortic valve           | 199 (89.6)                         | 96.8                | 0.839 (0.724—0.955)                    |
| Aortic arch, aortic valve to descending aorta          | 200 (90.1)                         | 95.5                | 0.748 (0.598—0.897)                    |
| Right ventricular outflow tract, pulmonary valve       | 199 (89.4)                         | 95.5                | 0.775 (0.641—0.909)                    |
| Pulmonary arteries (left and right, ductus arteriosus Botalli) | 197 (88.7)                         | 94.6                | 0.709 (0.554—0.864)                    |
| Pulmonary veins                                        | 190 (85.6)                         | 96.4                | 0.846 (0.742—0.950)                    |
| Venae cavae (inferior vena cava, superior vena cava)   | 205 (92.3)                         | 98.2                | 0.857 (0.720—0.994)                    |
| Pericardium                                            | 210 (94.6)                         | 98.2                | 0.809 (0.626—0.992)                    |

Values are expressed as number (percentage), interrater agreements (percentage) and Cohen’s kappa (95% confidence intervals). Image quality was rated independently by 2 radiologists as 1 for very good to good visibility of the structure(s), 2 for moderate but diagnostic, and 3 for nondiagnostic examination. Diagnostic examinations at 3T pmMRI are expressed as the sum of diagnostic scorings (scores 1 and 2), when none of the 2 raters stated the assessment of the respective cardiac structures as nondiagnostic (score 3). Interrater agreements and Cohen’s kappa values are based on independent scorings.

3T pmMRI, 3Tesla cardiac postmortem magnetic resonance imaging.

### TABLE 3
Concordance rates of 3T postmortem magnetic resonance imaging and prenatal ultrasound with autopsy for the diagnosis of congenital heart disease in 222 fetuses

| Variable                              | 3T pmMRI concordant | Prenatal US concordant | Fetuses per category | P-value 3T pmMRI | P-value Prenatal US |
|---------------------------------------|----------------------|------------------------|----------------------|------------------|---------------------|
| Gestational age (wk)                  |                      |                        |                      |                  |                     |
| <20 + 0                               | 46 (66.7)            | 44 (63.8)              | 69 (31.1)            | <.001            | <.001              |
| 20–23 + 6                             | 71 (94.7)            | 62 (82.7)              | 75 (33.8)            |                  |                     |
| ≥24 + 0                               | 66 (84.6)            | 69 (88.5)              | 78 (35.1)            |                  |                     |
| Birthweight (g)                       |                      |                        |                      |                  |                     |
| ≤100                                  | 21 (53.8)            | 23 (59.0)              | 39 (17.6)            | <.001            | .001               |
| 101–250                               | 23 (79.3)            | 20 (69.0)              | 29 (13.1)            |                  |                     |
| 251–500                               | 49 (92.5)            | 43 (81.1)              | 53 (23.9)            |                  |                     |
| >500                                  | 90 (89.1)            | 89 (88.1)              | 101 (45.5)           |                  |                     |
| Additional extracardiac malformations |                      |                        |                      | .079             | <.001              |
| No                                    | 71 (81.6)            | 69 (79.3)              | 87 (39.2)            |                  |                     |
| Yes, intrathoracic                    | 20 (69.0)            | 15 (51.7)              | 29 (13.1)            |                  |                     |
| Yes, extrathoracic                    | 92 (86.8)            | 91 (85.8)              | 106 (47.7)           |                  |                     |
| Mode of death                         |                      |                        |                      | .012             | .302               |
| Termination of pregnancy              | 73 (83.9)            | 66 (75.9)              | 87 (39.2)            |                  |                     |
| Feticide                              | 39 (88.6)            | 39 (88.6)              | 44 (19.8)            |                  |                     |
| Intrauterine fetal death              | 33 (67.3)            | 39 (79.6)              | 49 (22.1)            |                  |                     |
| Spontaneous abortion                  | 38 (90.5)            | 31 (73.8)              | 42 (18.9)            |                  |                     |

Values are expressed as number (percentage). P-values are based on Pearson’s χ²-test for independence, except for mode of death, which was based on Fisher’s exact test.

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weeks onward, with high interrater agreement. Exclusion of nondiagnostic imaging provided high sensitivity, specificity, and concordance rates of 3T pmMRI in the detection of CHD, in particular for nonseptal cardiac defects. However, image quality and, therefore, diagnostic accuracy depend on various factors. A deformed body shape after having wrapped the fetus for conservation hampers the differentiation of individual organs. Other limitations are harder to overcome, such as the lack of blood in the ventricles postmortem, which interferes with diagnostic imaging of the complete 4-chamber view. Intrathoracic abnormalities, such as diaphragmatic hernia or pleural effusion, have a similar detrimental effect on the feasibility of cardiac 3T pmMRI, because the side walls are squeezed toward the septa, which hampers the distinct imaging of both septa and atrioventricular valves. Furthermore, a well-designed protocol for 3T pmMRI, with planes adjusted to the cardiac axes and the outflow tracts, is essential, particularly with regard to their small size. Evaluation of the intrathoracic aorta is particularly difficult when the arch is dislocated or when a large arterial duct mimics the features of isthmus stenosis.

| Variable                  | 3T pmMRI concordant | Prenatal US concordant | Fetuses per category | P value |
|---------------------------|----------------------|------------------------|----------------------|---------|
| Days from death to 3T pmMRI |                      |                        |                      |         |
| 0–1                       | 114 (89.8)           | NA                     | 127 (57.2)           | .001    |
| 2                         | 38 (80.9)            | 47 (21.2)              |                      |         |
| 3                         | 19 (70.4)            | 27 (12.2)              |                      |         |
| >3                        | 12 (57.1)            | 21 (9.5)               |                      |         |
| Degree of maceration      |                      |                        |                      | .002    |
| 0–1                       | 134 (87.6)           | NA                     | 153 (68.9)           |         |
| 2                         | 20 (83.3)            | 24 (10.8)              |                      |         |
| 3                         | 29 (64.4)            | 45 (20.3)              |                      |         |

Values are expressed as number (percentage). Comparison between groups were performed using Chi-square test.

3T pmMRI, 3Tesla postmortem magnetic resonance imaging; NA, not applicable; US, ultrasound.

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FIGURE 2
Diagnostic quality rates of cardiac postmortem MRI for the detection of fetal congenital heart defects

Open white circles represent diagnostic quality rates when nondiagnostic images were rated as false-negative and blue circles represent the respective values when nondiagnostic images were excluded.

MRI, magnetic resonance imaging; NPV, negative predictive value; PPV, positive predictive value.

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TABLE 3
Concordance rates of 3T postmortem magnetic resonance imaging and prenatal ultrasound with autopsy for the diagnosis of congenital heart disease in 222 fetuses (continued)
and pulmonary veins are often hard to depict because they are commonly covered by other structures. More diagnostic MRI studies would have been available if the protocols for fetal 3T pmMRI (short interval between death and MRI, no wrapping of the body, specific protocol) had been followed.

### Clinical implications

The diagnostic accuracy of 3T pmMRI depends substantially on the decision about how to proceed with non-diagnostic examinations. Long latencies from demise to 3T pmMRI and autopsy, such as in cotwin demises with continuation of the pregnancy, are associated with high nondiagnostic 3T pmMRI rates. Removing those cases would raise the performance of 3T pmMRI in cases with a >3-day latency to be similar to those cases with a 3-day latency (70% vs 67%). When nondiagnostic cardiac 3T pmMRI examinations were considered false negative, the overall concordance of 3T pmMRI with autopsy in diagnosing a fetal CHD was 83.6%. Exclusion of nondiagnostic 3T pmMRI imaging led to significantly higher diagnostic quality rates, with a sensitivity of 87.8%, a specificity of 97.9%, and a concordance of 95.3%. We intentionally included all consecutive fetuses with 3T pmMRI and autopsy reports available to investigate clinical feasibility and diagnostic accuracy in the detection of CHD in the daily routine. Most previous studies either excluded nondiagnostic pmMRI imaging or included only fetuses without additional malformations or highly macerated bodies.\(^\text{15,18,19}\) In our opinion, this does not reflect the clinical situation of diverse fetal disease. Similar to other authors, we found the diagnostic value of cardiac 3T pmMRI less accurate in younger fetuses of lower birthweight.\(^\text{16–19}\) Furthermore, we observed high rates of nondiagnostic cardiac 3T pmMRI examinations in fetuses after spontaneous intrauterine death with a high degree of maceration, which resulted in high discordance rates (nondiagnostic 3T pmMRI vs diagnostic autopsy) in these fetuses. For fetuses younger than 20 weeks, 9.4T pmMRI\(^\text{18}\) and microfocus computed tomography (CT)\(^\text{21–24}\) have been suggested. Indeed, micro-CT scanners and high-field MRI scanners are not widely available. The procedure of minimally invasive

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### Table 4

Spectrum of fetal CHDs diagnosed on prenatal ultrasound, cardiac 3T pmMRI, and autopsy (1 fetus can have several cardiac anomalies)

| CHDs                                      | Specific diagnosis at: |       |       |       |
|-------------------------------------------|------------------------|-------|-------|-------|
|                                           | Prenatal ultrasound    | Cardiac 3T pmMRI | Autopsy |
| Conotruncal                               |                        |       |       |       |
| Tetralogy of Fallot and double-outlet right ventricle | 5 (63) | 4 (50) | 8      |
| d-Transposition of the great arteries     | 1 (100)                | 1 (100) | 1      |
| Common arterial trunk                     | 1 (100)                | 1 (100) | 1      |
| Right or double aortic arch               | 1 (25)                 | 3 (75) | 4      |
| Atrioventricular septal defect            | 6 (86)                 | 6 (86) | 7      |
| Septal defects                            |                        |       |       |       |
| Ventricular septal defect                 | 14 (67)                | 13 (62) | 21    |
| Atrial septal defect                      | 2 (40)                 | 2 (40) | 5      |
| Left ventricular outflow tract obstructions|                        |       |       |       |
| Coarctation of the aorta or aortic hypoplasia | 5 (36) | 10 (71) | 14    |
| Hypoplastic left heart syndrome           | 1 (100)                | 1 (100) | 1      |
| Right ventricular outflow tract obstructions|                       |       |       |       |
| Pulmonary artery stenosis or pulmonary artery atresia | 2 (67) | 2 (67) | 3      |
| Hypoplastic right heart syndrome          | 3 (100)                | 3 (100) | 3      |
| Cardiomyopathy                            | 2 (100)                | 2 (100) | 2      |
| Complex or other CHDs                     | 3 (60)                 | 4 (80) | 5      |
| All CHDs                                  | 46/75 (61)             | 52/75 (69) | 75    |
| CHD without ventricular septal defects and atrial septal defects | 30/49 (61) | 37/49 (76) | 49    |

Values are expressed as number (percentages). The values indicate the number of cases found with each respective modality, the numbers in parentheses represent the percentage of the detected pathologies relative to full autopsy.

3T pmMRI, 3Tesla postmortem magnetic resonance imaging; CHD, congenital heart defects.

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autopsy, including 1.5T pmMRI, defined by Thayyil et al,9 has about the same diagnostic accuracy for the detection of major abnormalities as conventional autopsy, even in younger fetuses. However, undetected abnormalities were predominantly located in the lungs and the heart, most frequently reported in young fetuses at 24 weeks’ gestation or less.9 The approach with 3T pmMRI provides sufficient image quality with high resolution of anatomic structures, is more widely accessible, and allows a suitable postmortem examination both for young and for older fetuses with the advantage of a high soft-tissue resolution compared with CT.

Research implications
Fetal postmortem evaluation is crucial, and considering the decline in parental consent for invasive investigation and the increased pathologist’s workload, targeted autopsy in selected fetuses may aid both families and clinicians. 3T pmMRI provides almost the same degree of accuracy as conventional autopsy and is widely available, and images may be transferred from anywhere to specialized centers with expertise in pre- and perinatal medicine. Considering these facts, we urgently need further studies in this field to upgrade postmortem imaging as an integral part of the clinical routine.

Strengths and limitations
Previous investigations of the diagnostic accuracy of pmMRI excluded a substantial proportion of fetuses owing to unavailable autopsy records.14,25 A major strength of this study is the inclusion of a large, consecutive cohort of fetuses with 3T pmMRI, of which only 4.2% had to be excluded owing to missing autopsy data. In Austria, the law permits non-forensic autopsies without family consent when there is a medical or scientific interest; therefore, autopsy rates in Austria are high compared with other countries.26 The major limiting factor for cardiac evaluation in this study was the inhomogeneous 3T pmMRI examination protocols adjusted to extra-thoracic body regions, predominantly the fetal brain. Only 51.8% of fetuses...
had 3T pmMRI sequences that allowed for reconstruction in all orthogonal planes and, thus, could adequately display all cardiac axes. To study the feasibility of cardiac 3T pmMRI, the radiologists in the present investigation were blinded to any clinical data; it is likely that the knowledge of these factors would further improve the 3T pmMRI test characteristics. However, most 3T pmMRI examinations were diagnostic with regard to CHD, which underlines the strength of this method.

Conclusions

3T pmMRI is a feasible tool with which to evaluate the fetal heart and to detect CHD at any gestational age. Diagnostic imaging rates were particularly high in fetuses with a birthweight of >100 g, a gestational age of >20 weeks, low-degree maceration, and after a <3-day interval from death to pmMRI. After excluding nondiagnostic imaging, specificity for the detection of CHD was high, especially with regard to nonseptal cardiac anomalies. Cardiac 3T pmMRI may act as a decision tool as to whether or not to proceed with invasive postmortem investigation, such as conventional autopsy. The targeted use of postmortem imaging techniques provides quality assurance for prenatal assessments and important additional information about the causes of death while reducing the workload for pathologists. Telemedical evaluation of postmortem imaging would even free diagnostic analyses from the place where the data were acquired.

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Author and article information
From the Division of Obstetrics and Fetomaternal Medicine, Department of Obstetrics and Gynecology (Drs Ulm and Muin), Department of Biomedical Imaging and Image-Guided Therapy (Drs Dovjak, Prayer, Weber, and Berger-Kulemann), Department of Pathology (Dr Scharrer), and Department of Cardiac Surgery (Dr Zimpfer), Medical University of Vienna, Vienna, Austria.
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Corresponding author: Barbara Ulm, MD. barbara.ulm@meduniwien.ac.at
Supplementary Material

Autopsy and magnetic resonance imaging protocols, further cardiac pathologies and details on fetal malformations

A. Protocol for fetal and perinatal autopsies

A senior fetal and perinatal pathologist (A.S.) with more than 15 years of experience in fetal and perinatal pathology performed autopsy in all cases according to a predesigned protocol.

The protocol followed (with individual modification if necessary) the following:

- Handbook of Pediatric Autopsy Pathology, 2nd Edition, Springer Media, ISBN 978-1-4614-6710-6
- Keeling’s Fetal and Neonatal Pathology, 5th Edition, Springer Media, ISBN 978-3-319-19207-2
- Autopsie Leitfaden, Facultas Verlag, ISBN978-3-7089-1885-3
- Pediatric Cardiology, 3rd Edition, Churchill Livingston /Elsevier Ltd ISBN 978-0-7020-3064-2

Autopsy (selected for internal examination and cardiovascular system) included at minimum, but was not restricted to:

Internal examination

- Comment on cranial, thoracic and abdominal cavities
- Retention and fixation of the brain where practicable
- Systematic description of major organs and tissues
- Specific reference to ductus arteriosus and umbilical vessels
- Weights of all major organs in a digital balance (to 0.1 g)
- Comment on muscle and skeleton

Cardiovascular system

- Pericardium including effusion
- Myocardium: atria and ventricles
- Coronary arteries including orifices
- Valves
- Aorta
- Major branches of aorta
- Pulmonary arteries and veins
- Inferior and superior vena cavae, other major and systemic veins

B. Protocol for 3Tesla postmortem magnetic resonance imaging

Imaging parameter for cardiac 3Tesla postmortem magnetic resonance imaging on the 3T scanner SIEMENS MAGNETOM VIDA-XT-128, Siemens, Erlangen, Germany. Examination protocols were adjusted to the pathologies found in prenatal ultrasound and previous fetal magnetic resonance imaging examinations. In the first 18 months of postmortem imaging we used a T2-weighted sequence in the axial and coronal plane to assess the body. Since the end of 2013, we in addition used a 3-dimensional (3D) constructive interference in steady state (CISS) sequence enabling multiplanar reconstructions in various planes.

C. Further cardiac pathologies seen on 3T pmMRI

D. Details on multiple fetal malformations and skeletal dysplasias (Supplemental Table 2)

| Sequence     | Voxel size       | TE   | TR    | FOV   | SL  | FA  |
|--------------|------------------|------|-------|-------|-----|-----|
| 2D T2-weighted | 0.3×0.3×0.4 mm³ | 122.0 ms | 1000 ms | 130–140 mm | 0.4 mm | 100° |
| 3D CISS      | 0.4×0.4×0.4 mm³ | 3.17 ms | 7.04 ms | 157–230 mm | 0.4 mm | 46° |

FA, flip angle; FOV, field of view; SL, slice thickness; TE, echo time; TR, repetition time.

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SUPPLEMENTAL FIGURE 1
Atrial septal defect

Postmortem T2-weighted 4-chamber view in a fetus with an atrial septal defect type I in gestational week 23+3. The defect represented by asterisk between the RA and LA can be visualized very well. In addition, the blood-fluid level is continuous through both atria.

LA, left atrium; RA, right atrium.
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SUPPLEMENTAL FIGURE 2
Tetralogy of Fallot

Postmortem T2-weighted parasagittal slice of a fetus with tetralogy of Fallot in gestational week 36+0. The overriding aorta represented by asterisk can be seen well.

Ao, ascending aorta.
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SUPPLEMENTAL FIGURE 3
Hypoplastic left heart

Postmortem T2-weighted 4-chamber view in a fetus with hypoplastic left heart syndrome in gestational week 20+6. The enlarged RA and the RV can be seen well. The asterisk marks the hypoplastic left ventricle which is only minimally filled with fluid.

RA, right atrium; RV, right ventricle.

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SUPPLEMENTAL FIGURE 4
Hypoplastic right heart

Postmortem T2-weighted 4-chamber view in a fetus with hypoplastic right heart syndrome in gestational week 23+5. The arrow marks the hypoplastic right ventricle.

LV, left ventricle.

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SUPPLEMENTAL FIGURE 5
Pulmonary atresia

Postmortem T2-weighted coronal slice of a fetus with pulmonary atresia in gestational week 18+6. The asterisk marks the thin pulmonary trunk, and the arrows the course of the hypoplastic right pulmonary artery.

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SUPPLEMENTAL FIGURE 6
Truncus arteriosus

T2-weighted oblique-sagittal reconstruction of a fetus with truncus arteriosus communis in gestational week 26+1. Both the ascending aorta, and the pulmonary trunk arise from a common trunk (arrow).

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SUPPLEMENTAL FIGURE 7
Ventricular septal defect

Postmortem T2-weighted 4-chamber view in a fetus with a ventricular septal defect represented by asterisk in gestational week 23+2. The arrows mark the lung veins on both sides.

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SUPPLEMENTAL FIGURE 8
Coarctation of aorta

T2-weighted oblique-sagittal view (parallel to the aortic arch) of a fetus with coarctation of the aorta in gestational week 33+0. The tapering in the proximal descending aorta and the coarctation (arrow) can be delineated well. The 3 asterisks mark the supraaortal branches (brachiocephalic trunk, left common carotid artery, and left subclavian artery).

Ao, descending aorta.

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## Overview of autopsy findings in fetuses where multiple malformations or skeletal dysplasia are noted

This table summarizes the main autopsy findings in fetuses with multiple malformations or skeletal dysplasia, as noted on Supplemental Table 2. Each entry includes the case ID, main findings, and additional details relevant to the specific case.

| Case ID from Supplemental Table 2 | Main autopsy findings (summative). |
|-----------------------------------|-----------------------------------|
| 15⁺₂, 37 g, IUFD                 | Flexion deformity at the second and fourth fingers (bilateral) |
|                                  | Cardiac malformation: tetralogy of Fallot |
| 15⁺₂, 50 g, TOP                  | Sequence of the missing umbilical cord |
|                                  | Amniotic peritoneal tube with exposed abdominal organs (liver, spleen, intestine, stomach) |
|                                  | Split pelvis |
|                                  | External genitals and internal genital organs and the urinary bladder cannot be displayed |
|                                  | Ventricular septal defect |
|                                  | Lumbar spine scoliosis |
|                                  | External rotation of both legs, clubfeet |
| 15⁺₅, 72 g, TOP                  | Skin edema, hygroma colli, hypertelorism, deep set ears, bilateral cleft lip and palate |
|                                  | Tetralogy of Fallot with right cardiac hypertrophy, pulmonary stenosis, ventricular septal defect, overriding aorta |
|                                  | Left-sided diaphragmatic hernia with intrathoracic left liver lobe, parts of the stomach and spleen |
|                                  | Hypoplastic lung (left) |
| 17⁺₂, 95 g, TOP                  | Discrete craniofacial dysmorphia |
|                                  | Omphalocele with eversion of the entire gastrointestinal tract to sigmoid colon, spleen, liver, pancreas and left-sided diaphragmatic defect |
|                                  | Ventricular septal defect, coarctation of the aorta |
|                                  | Dilated internal cerebrospinal fluid spaces and cystic choroid plexus |
| 18⁺₆, 216 g, TOP                  | Hydrocephaly, complex malformation syndrome, |
|                                  | Dysplastic thumb (right), thymic agenesis |
|                                  | Monolobar right lung |
|                                  | Hypoplastic right heart syndrome, atresia of the tricuspid and the pulmonary valve, narrow truncus pulmonalis, large atrial septal defect |
|                                  | Arteria lusoria |
|                                  | Renal agenesis (right), discoid adrenal gland (right) |
|                                  | Uterine agenesis |
|                                  | Scoliosis |
|                                  | Single umbilical artery (left-sided), hypoplastic placenta |
| 19⁺₃, 200 g, TOP                  | Discrete external dysmorphism: minimal hypertelorism, micrognathia |
|                                  | Pes equinovarus on both sides |
|                                  | Subcutaneous edema, discrete pleural effusion on both sides |
|                                  | Discrete lung hypoplasia on both sides, 2-lobed right lung |
|                                  | Hydrops |
|                                  | Free ascending colon |
|                                  | Pelvic testicles on both sides |

Ulm et al. Postmortem magnetic resonance imaging of the fetal heart. Am J Obstet Gynecol 2021. (continued)
| Case ID from Supplemental Table 2 | Main autopsy findings (summative). |
|----------------------------------|-----------------------------------|
| 20+6, 290 g, TOP                | Typical Potter facies in anhydramnios, deformed extremities and contractures, Hygroma colli Double-outlet right ventricle with relatively small left ventricle, ventricular septal defect and right-sided aortic arch Bilateral lung hypoplasia, hydrothorax Accessory spleen, spinal malformation, Bilateral renal agenesis |
| 21+2, 347 g, TOP                | Deep set ears Complete agenesis of corpus callosum Hypertelorism, microretrognathia Hexadactyly bilateral, upper and lower extremities Omphalocele with herniated loops of the small intestine/Meckel’s diverticulum Ventricular septal defect Ureter duplex (left) Bicornuate uterus |
| 21+6, 560 g, TOP                | Oligohydramnios sequence: Potter facies, contractures of large joints, rocker bottom feet both sides, generalized subcutaneous edema, Bilateral hypoplastic kidneys with small cysts, small ureters, small urinary bladder Cystic hygroma colli (especially dorsal) Narrow thorax, bilateral lung hypoplasia Coarctation of the aorta Cardiac dilation, stasis organs |
| 22+1, 280 g, TOP                | Occipital encephalocele (3 cm in diameter); short neck, high palate Kyphoscoliosis with hemispherical and block vertebrae (thoracolumbar) Diaphragmatic aplasia (left) with thoracic displacement of the left liver, Pancreas, spleen, gastrointestinal tract to descending colon, mediastinal shift and bilateral lung hypoplasia Ventricular septal defect, dysphagia lusoria Pelvic testicles on both sides |
| 22+2, 380 g, TOP                | Massive hygroma colli Hyperelorism Left-sided diaphragmatic hernia with an intrathoracic stomach, spleen, loops of small intestine, and left liver lobe Coarctation of the aorta Ventricular septal defect Bilateral pulmonary hypoplasia Bilateral multicystic hypoplastic kidneys Bicornuate uterus |

Ulm et al. Postmortem magnetic resonance imaging of the fetal heart. Am J Obstet Gynecol 2021. (continued)
### Overview of autopsy findings in fetuses where multiple malformations or skeletal dysplasia are noted on Supplemental Table 2 (continued)

| Case ID from Supplemental Table 2 | Main autopsy findings (summative). |
|-----------------------------------|-----------------------------------|
| 22+3, 365 g, TOP                  | Craniofacial dysmorphia with atypical Naso-orbital complex, hypotelorism, short eyelid slits, small mouth, Narrow lips, small chin Ventricular septal defect, right cardiac dilation, Prominent ductus arteriosus Botalli and discrete hypoplasia/coarctation of the aortic arch Bilateral plexus cysts Diaphragmatic furrows of the liver, Meckel’s diverticulum Small adrenal glands, small thyroid and pancreas Generalized congestive hyperemia, subcapsular liver hematoma |
| 23+2, 486 g, TOP                  | OEIS complex: omphalocele, cloacal extrophy, anal atresia, intestinal malrotation, lumbosacral meningocele Secondary scrotum fissus Pelvic kidney on the right side Tetralogy of Fallot with right-sided aortic arch Upper extremity contractures Clubfeet (left>right) |
| 23+2, 560 g, TOP                  | Hydrocephaly, small face skull Deep set ears, flexion deformities, prominent heels Complex cardiac defect with atrial and ventricular septal defect Bilobar lung on the right side Esophageal atresia type IIIb according to Vogt Ascites Single umbilical artery |
| 23+3, 505 g, TOP                  | Pierre Robin sequence with craniofacial dysmorphia, Hydrocephaly, low set ears bilateral, hypertelorism, antimongoloid lid axis position Microstomy, micrognathia, median cleft palate Atrial septal defect I Massive bilateral pulmonary hypoplasia |
| 23+4, 612 g, Feticide             | Left isomerism with Dandy Walker syndrome Right-sided aortic arch and descending aorta, Double-outlet right ventricle with ventricular septal defect Left isomerism of tracheal bifurcation (with 2-lobed lungs) and isomerism of cardiac auricles Partial situs inversus abdominis: stomach, spleen and pancreas on the right side Malrotation of the mesenteric root Ascites |

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## Overview of autopsy findings in fetuses where multiple malformations or skeletal dysplasia are noted on Supplemental Table 2 (continued)

| Case ID from Supplemental Table 2 | Main autopsy findings (summative). |
|-----------------------------------|-----------------------------------|
| 24+1, 515 g, TOP                  | Brachycephaly, bilateral cleft lip and palate, semilobar holoprosencephaly |
|                                   | Atrial septal defect II           |
|                                   | Massive hepatosplenomegaly with bleeding and necrosis of the liver |
|                                   | Relatively large kidneys with prominent renulation, atypical renal pelvis, hypoplastic ureters, small urinary bladder |
|                                   | Small adrenal glands, small lungs |
|                                   | Cardiac dilation, ascites, pericardial effusion |
|                                   | Cantilever feet                  |
| 25+6, 1040 g, Feticide            | Skeletal dysplasia (clinical: diastrophic dysplasia) |
|                                   | External dysmorphism with significantly shortened extremities (especially proximal), bilateral cradle feet |
|                                   | Hypertelorism, prominent forehead, sunken nasal saddle, small chin |
|                                   | Diastrophic dysplasia,           |
|                                   | Coarctation of the aorta (30% lumen reduction) |
|                                   | Subcutaneous edema               |
| 26+4, 1320 g, NND                 | Hydrops with massive pleural effusion on both sides (drained) and massive cor contractum |
|                                   | Pericardial effusion             |
|                                   | Bilateral pulmonary hypoplasia, interstitial (finely lobulated) |
|                                   | Pulmonary emphysema, multifocal pulmonary hemorrhage, mediastinal emphysema |
|                                   | Cardiovascular malformation: double aortic arch with |
|                                   | retroesophageal “ring formation” (left aortic arch hypoplastic with atresia before DAB), bicuspid aortic valve |
|                                   | Anasarca (head and neck stressed) |
| 29+0, 836 g, NND                  | Condition after anhydramnios: small chin, cradle feet on both sides |
|                                   | All long tubular bones shortened |
|                                   | Massive bilateral pulmonary hypoplasia |
|                                   | Hypoplastic ureters and bladder |
|                                   | Large atrial septal defect II, cardiac hypertrophy (right heart), cardiac dilation |
|                                   | Slightly hypoplastic cystic kidneys on both sides (see histo) |
|                                   | Atypical “overlapping” toe line on both sides |
|                                   | Anasarca, hydrothorax, hydrops universalis |
|                                   | Ambiguous external genitalia, testicular rudiments in the inguinal canal |
| 30+5, 1420 g, feticide            | Heterozygous deletion 17q25.3 with cleft lip and palate and vitium cordis |
|                                   | Hypertelorism                     |
|                                   | 4-finger furrow on both sides     |
|                                   | Bilateral cleft lip and palate    |
|                                   | Complex cardiac defect (Double-outlet right ventricle with ventricular septal defect and small left ventricle) |
|                                   | Chest wall hematoma, soft-tissue hematoma mediastinal, hematothorax, hematopericardium |
### Overview of autopsy findings in fetuses where multiple malformations or skeletal dysplasia are noted on Supplemental Table 2 (continued)

| Case ID from Supplemental Table 2 | Main autopsy findings (summative). |
|-----------------------------------|-----------------------------------|
| 31 +4, 1250 g, feticide           | Semilobar holoprosencephaly and arhinencephaly |
|                                   | Microcephaly, microphthalmia and hypotelorism, missing nasal septum, high, pointed palate |
|                                   | Right hand quadruple with preaxial appendages, left hand with syndactyly 2/3 |
|                                   | Type I esophagotracheal fistula |
|                                   | Ventricular septal defect |
|                                   | Horseshoe kidneys |
|                                   | Hypoplastic placenta with single umbilical artery |
| 31 +6, 2650 g, feticide           | Multiple malformations and complex cardiac malformation |
|                                   | External dysmorphism: 4-finger furrow, hydrocephalic skull configuration |
|                                   | Fontanelles with bilateral osseous deficiency, plump nasal saddle (missing nasal bone), slight hypertelorism and mongoloid lid axis position, cradle feet on both sides |
|                                   | Hydrocephalus internus et externus, old media infarction with massive reduction of the cerebral cortex |
|                                   | Atrioventricular septal defect, persistent ductus arteriosus Botalli, coarctation of the aorta |
|                                   | Hematopericardium |
|                                   | Atypical big toes on both sides, conical fingers and prominent fingertips |
| 33 +0, 960 g, NND                 | Dysmorphism suspicious of trisomy 18: dolichocephaly, dysplastic auricles on both sides, |
|                                   | narrow lips, small mouth, hypertelorism, misalignment of the fingers on both sides (flexion contractures), |
|                                   | prominent calcaneus on both sides |
|                                   | Esophageal atresia type 3b according to Vogt (proximal blind sac, distal fistula) |
|                                   | Perimembranous ventricular septal defect, persistent ductus arteriosus Botalli, cardiac hypertrophy, coarctation of aorta |
|                                   | Diaphragmatic furrows of the liver, pronounced square lobe with small calcification |
|                                   | Small adrenal glands with premature involution, sparsely renaled kidneys |
|                                   | Noticeably narrow/contracted small and large intestines (with the exception of the oral small intestine), Meckel’s diverticulum |
| 35 +2, 2525 g, IUFD               | Female stillbirth |
|                                   | Anhydramnios sequence: Potter facies, dysplastic auricles |
|                                   | Bell-shaped narrow thorax, bilateral lung hypoplasia and lung bleedings |
|                                   | Contractures, scoliosis |
|                                   | Massive splenomegaly with no discernible white pulp |
|                                   | Cardiac dilatation (cardiomyopathy), especially on the left side, pericardial effusion, |
|                                   | Hypoplastic kidneys, secondary hypoplasia of the ureters and urinary bladder |
|                                   | Hydropic placenta |
|                                   | Relatively short extremities, large fontanelles |

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| Case ID from Supplemental Table 2 | Main autopsy findings (summative). |
|----------------------------------|-----------------------------------|
| 36+0, 1760 g, feticide           | Cardiac malformation: double-outlet right ventricle and ventricular septal defect, overriding aorta |
|                                  | Suspicious for posterior cleft palate and suspicious for Pierre Robin syndrome |
|                                  | Single umbilical artery |
|                                  | Left kidney shifted caudally |
|                                  | Microretrognathia |
|                                  | Mega cisterna magna and pontocerebellar hypoplasia |
|                                  | Cerebellar hypoplasia, Pons hypoplasia |
| 36+4, 1790 g, NND                | Suspected thanatophoric skeletal dysplasia type II |
|                                  | Brachydactyly |
|                                  | Generalized shortening of the long bones |
|                                  | Bell-shaped, narrow thorax; Pulmonary hypoplasia and hemorrhage |
|                                  | Massive secondary bilateral pulmonary hypoplasia |
| 36+4, 2930 g, NND                | Thanatophoric dwarfism type I with typical skeletal deformity |
|                                  | Temporal lobe hypertrophy bilateral, symmetrical, mediobasal |
|                                  | Cortical development disorders in dorsal parts of the brain |
|                                  | Megalencephalic malformation syndrome |
|                                  | Severe bilateral lung hypoplasia |
|                                  | Severe acrocyanosis |
| 37+4, 1651 g, IUFD               | Suspicious for Roberts syndrome, craniofacial dysmophia |
|                                  | Suspicious for musculoskeletal malformation syndrome (bilateral cleft lip and palate cleft; exophthalmos; deep-seated auricles; forearm/hand malformation, anal atresia) |
|                                  | Trilobar lung (left side) |
|                                  | Retrognathia, mandibular hypoplasia, bilateral phocomelia of the upper extremities |
|                                  | Accessory spleen |
|                                  | Hypospadias |
| 37+5, 2140 g, NND                | Proportionate generalized hypotrophy, male newborn |
|                                  | Craniofacial dysmophia with microcephaly, high forehead, microphthalmia, deep nasal root, hypotelorism |
|                                  | Deep-seated ears, bilateral complete cleft lip and palate |
|                                  | Semilobar holoprosencephaly, arhinencephaly, small pons with thickened tectum and tegmentum |
|                                  | Complex cardiac defect with single outlet right ventricle, pulmonary atresia and ventriculoarterial discordance, ventricular septal defect, small atrial septal defect II and hypoplasia of the pulmonary artery |
|                                  | Incomplete lung lobation (right side) |
|                                  | Meckel’s diverticulum |
|                                  | Hydronephrosis dext. with ureter fissus and megahydroureter and ureteral stenosis at the urinary bladder ostium |
## Overview of autopsy findings in fetuses where multiple malformations or skeletal dysplasia are noted on Supplemental Table 2. (continued)

| Case ID from Supplemental Table 2 | Main autopsy findings (summative). |
|-----------------------------------|-----------------------------------|
|                                   | Hexadactyly bilateral, upper and lower extremities |
|                                   | Maldescensus testis bilateral |
|                                   | Hypoplastic placenta with single umbilical artery |

IUFD, intrauterine fetal death; NND, neonatal death; TOP, termination of pregnancy.

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### SUPPLEMENTAL TABLE 1

**Detailed characteristics of the study population (n = 222)**

| Parameters                                      | Values                        |
|-------------------------------------------------|-------------------------------|
| **Maternal characteristics (n = 220)**           |                               |
| Maternal age, y                                 | 32 (18—51)                    |
| Prepregnant body mass index, kg/m²<sup>a</sup>   | 24.5 (17.5—52.2)              |
| Obese (body mass index > 30)                    | 35/199 (17.6)                 |
| Gravidity                                       | 2 (1—9)                       |
| Parity                                          | 1 (0—7)                       |
| Smoker                                          | 29 (13.2)                     |
| Twin pregnancy<sup>b</sup>                      | 9/220 (4.1)                   |
| Complications of placenta or umbilical cord<sup>c</sup> | 9 (4.1)<sup>d</sup>            |
| Complications of twinning<sup>d</sup>           | 8 (3.6)<sup>d</sup>            |
| IUFD or NND unexplained                         | 3 (1.4)<sup>d</sup>           |
| **Mode of delivery and fetal characteristics (n = 222)** |                               |
| + vaginal (after prostaglandin induction of labor) | 208 (93.7)                    |
| + cesarean delivery                             | 14 (6.3)                      |
| Male fetus                                      | 104 (46.8)                    |
| Fetal weight (g)                                | 444 (10—3800)                 |
| Fetal length (cm)                               | 27 (5—55)                     |

Values are expressed as median (range) or number (percentage).

<sup>a</sup> In 21 cases, the maternal body mass index was unknown (21/220, 9.5%);<sup>b</sup> 11 fetuses or neonates were included in the 3T pmMRI study, and 7 healthy neonates were not included;<sup>c</sup> Included placental abruption and umbilical cord knot, without problems of twinning;<sup>d</sup> None of these cases exhibited a fetal or neonatal congenital heart defect at autopsy;<sup>e</sup> Included 1 dichorionic twin pregnancy with late miscarriage of both fetuses, 2 monochorionic twin pregnancies with intrauterine death of 1 twin and survival of the other, 2 monochorionic twin pregnancies with early twin-twin transfusion syndrome and demise of all 4 fetuses (3 included in the 3T pmMRI study), and 1 monochorionic twin pregnancy after laser treatment of twin-twin transfusion syndrome and demise of 1 twin.

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### SUPPLEMENTAL TABLE 2
Details of fetal cardiac MFs evaluated by prenatal ultrasound, 3Tesla postmortem magnetic resonance imaging, and autopsy

| GA  | BW (g) | Mode of death | Prenatal ultrasound | 3T pmMRI | Autopsy | Additional Anomalies | Interval death to pmMRI/autopsy (d) | Degree of maceration |
|-----|--------|---------------|---------------------|----------|---------|---------------------|-------------------------------------|---------------------|
| 13+1| 10.4   | TOP           | ND                  | 1 heart, 2 AoA | 1 heart, 2 AoA | Craniothoracopagus | 2/3                                 | 0                   |
| 13+2| 25     | IUFD          | abnormal            | ND        | TOF     | Trisomy 18          | 0/4                                 | 2                   |
| 14+1| 28     | TOP           | ND                  | ND        | AIST    | 45, X0, hydrothorax, hydropic | 0/4                                 | 0                   |
| 14+2| 22     | TOP           | ND                  | ND        | AIST    | Trisomy21, cystic hygroma | 1/5                                 | 0                   |
| 14+4| 95     | TOP           | ND                  | AVSD, RV>LV, AIST | AVSD, AIST |                     | 0/7                                 | 0                   |
| 15+1| 55     | TOP           | ND                  | AIST      | AIST    | Megacystis          | 0/4                                 | 0                   |
| 15+2| 37     | IUFD          | HLHS                | ND        | TOF     | Trisomy18, mult. MF | 2/5                                 | 0                   |
| 15+2| 50     | TOP           | ND                  | ND        | VSD     | Mult. MF            | 1/4                                 | 0                   |
| 15+4| 87     | TOP           | AVSD                | AVSD      | VSD     | Ellis-van Creveld syndrome | 0/1                                 | 0                   |
| 15+5| 72     | TOP           | ND                  | ND        | TOF     | DH (left), mult. MF | 1/0                                 | 0                   |
| 15+6| 79     | TOP           | ARSA                | normal/limited | normal | DH (left), spina bifida | 4/5                                 | 0                   |
| 16+3| 113    | TOP           | AVSD                | normal    | normal | Trisomy 21          | 1/4                                 | 0                   |
| 16+6| 145    | TOP           | VSD                 | VSD       | VSD     | Trisomy 21          | 1/4                                 | 0                   |
| 17+2| 95     | TOP           | Ti                  | AIST      | AIST, VSD | Trisomy 18, mult. MF | 1/3                                 | 0                   |
| 17+3| 110    | TOP           | VSD                 | ND        | VSD     | Trisomy 18, omphalocele | 1/2                                 | 0                   |
| 17+4| 150    | TOP           | VSD                 | ND        | normal  | 45,X0, hydropic | 2/2                                 | 0                   |
| 18+0| 202    | TOP           | ASVD, Ti            | AVSD, RA dilated, RV hypertrophy | AVSD, RV hypertrophy | Trisomy 21, DWM | 0/3                                 | 0                   |
| 18+3| 205    | TOP           | ND                  | AVSD      | normal | Trisomy 21          | 2/3                                 | 0                   |
| 18+3| 225    | TOP           | AVSD                | AVSD, ASD II | AVSD, ASD II | Trisomy 21-Mosaic | 0/3                                 | 0                   |
| 18+4| 223    | TOP           | normal              | normal    | VSD, AIST | Trisomy21          | 1/4                                 | 0                   |
| 18+6| 216    | TOP           | HRHS                | HRHS, hypoplastic PA | HRHS, hypoplastic PA, ASD | Mult. MF | 4/5                                 | 0                   |
| 19+3| 200    | TOP           | VSD                 | normal    | normal | Mult. MF, hydropic | 0/3                                 | 0                   |
| 20+2| 270    | TOP           | HRHS                | HRHS      | HRHS    | no                  | 1/5                                 | 0                   |

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### SUPPLEMENTAL TABLE 2
Details of fetal cardiac MFs evaluated by prenatal ultrasound, 3Tesla postmortem magnetic resonance imaging, and autopsy (continued)

| GA  | BW (g) | Mode of death | Prenatal ultrasound | 3T pmMRI | Autopsy | Additional Anomalies | Interval death to pmMRI/autopsy (d) | Degree of maceration |
|-----|--------|---------------|---------------------|----------|---------|---------------------|-------------------------------------|----------------------|
| 20+6| 290    | TOP           | DORV, hypoplastic   | DORV, LV not filled, LV, hypoplastic aorta | DORV, VSD, hypoplastic, LV, right AoA | 16q22.2 deletion, hydrothorax, mult. MF | 1/2 | 0 |
| 21+2| 347    | TOP           | Borderline LV       | VSD      | VSD     | Trisomy 13, mult. MF | 3/4 | 0 |
| 21+2| 764    | TOP           | HLHS, MI, LA        | HLHS, LA | HLHS, LA | Pericardial effusion | 1/2 | 0 |
| 21+3| 206    | TOP           | normal              | AIST     | AIST    | FGR                 | 1/5 | 0 |
| 21+6| 560    | TOP           | VSD; hypoplastic aorta | PLSVC   | AIST    | Mult. MF            | 1/2 | 0 |
| 22+0| 591    | Feticide      | Rhabdomyoma         | AIST     | AIST, diluted DAB | AIST, dilated DAB | Trisomy 18-Mosaic, mult. MF | 2/3 | 0 |
| 22+1| 280    | TOP           | normal              | VSD      | VSD     | DH (left), mult. MF | 0/2 | 0 |
| 22+2| 380    | TOP           | normal              | normal   | AIST, VSD | DH (left), mult. MF | 0/5 | 0 |
| 22+3| 365    | TOP           | VSD, hypoplastic LV, | VSD, dilated RV, | VSD, dilated RV, | Trisomy 18-Mosaic | 2/3 | 0 |
| 22+6| 605    | Feticide      | AVSD                | AVSD     | AVSD, AIST | Trisomy 21 | 1/2 | 1 |
| 23+2| 486    | TOP           | ND                  | TOF, right AoA | TOF, right AoA | Mult. MF | 0/2 | 0 |
| 23+2| 560    | TOP           | VSD                 | VSD; ASD | VSD, ASD | Trisomy 18, mult. MF | 0/3 | 0 |
| 23+2| 740    | Feticide      | VSD, hypoplastic Ao, | VSD, absent AoA, | VSD, hypoplastic Ao, | Microdeletion 22q11.2 | 2/6 | 0 |
| 23+3| 505    | TOP           | VSD, ASD            | ASD      | ASD I    | 3p-minus-Sy., mult. MF | 3/5 | 0 |
| 23+4| 612    | Feticide      | Heterotaxy, VSD     | DORV, VSD, overriding aorta | DORV, VSD, right AoA | Mult. MF | 3/6 | 2 |
| 23+5| 448    | TOP           | HRHS                | HRHS     | HRHS     | Microdeletion 22q11.2 | 1/2 | 0 |
| 23+5| 530    | Feticide      | Absent PV, dilated  | Absent PV, dilated, PA's, abs.DAB, VSD | Absent PV, dilated, PA's, abs.DAB, VSD | Trisomy 13, mult. MF | 0/5 | 0 |
| 24+1| 515    | TOP           | VSD, dilated PA, Hypoplastic aorta | AIST | ASD | Trisomy 13, mult. MF | 0/5 | 0 |
| 25+2| 670    | Feticide      | normal              | normal   | AIST     | Microdeletion 4q21.3q23 | 2/3 | 2 |

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| GA  | BW (g) | Mode of death | Prenatal ultrasound | 3T pmMRI | Autopsy | Additional Anomalies | Interval death to pmMRI/autopsy (d) | Degree of maceration |
|-----|--------|---------------|---------------------|----------|---------|----------------------|-----------------------------------|---------------------|
| 25+6| 870    | Feticide      | valvular PS, dysplastic | hypoplastic PA, TV, hypoplastic RV | Valvular PS | no | 2/5 | 3 |
| 25+6| 1040   | Feticide      | normal              | normal   | AIST    | Skeletal dysplasia   | 2/4 | 0 |
| 26+0| 814    | Feticide      | d-TGA, VSD, ASD    | d-TGA, ASD II | DH (left)^a | 1/4 | 1 |
| 26+1| 880    | Feticide      | Common arterial trunk, VSD | trunk, VSD | Common arterial trunk, VSD | Microdeletion 22q11.2 | 2/3 | 2 |
| 26+4| 1320   | NND           | Right AoA           | Double AoA | Double AoA | Mult. MF | 1/1 | 0 |
| 27+2| 484    | Feticide      | AVSD, cardiomegaly | ND       | AVSD, ASD II | DC twins, FC 2 mo before delivery, hydropic | 60/60 | 3 |
| 27+6| 870    | Feticide      | VSD, dilated PA     | Dilated DAB, hypoplastic aorta | VSD, AIST | Trisomy 18-Mosaic | 2/4 | 1 |
| 29+0| 836    | NND           | Valvular PS, VSD    | AIST     | ASD II, right heart hypertrophy | Skeletal dysplasia, mult. MF, hydrothorax^a | 0/4 | 0 |
| 30+5| 1420   | Feticide      | DORV, hypoplastic LV, hypoplastic aorta | DORV, hypoplastic LV, hypoplastic aorta | VSD | Microdeletion 17q25.3 | 2/4 | 3 |
| 31+2| 1380   | IUFD          | VSD                 | VSD      | VSD     | Polyhydramnios      | 2/3 | 1 |
| 31+4| 1250   | Feticide      | VSD                 | VSD      | VSD     | Trisomy 13, mult. MF | 2/4 | 3 |
| 31+6| 2650   | Feticide      | AVSD                | AVSD     | AVSD, AIST | Trisomy 21, mult. MF | 1/2 | 1 |
| 32+6| 1456   | NND           | VSD                 | PL SVC   | PL SVC   | Triploidy, hydropic | 1/3 | 0 |
| 33+0| 960    | NND           | AIST, VSD           | AIST, VSD | AIST, VSD | Trisomy 18, mult. MF | 1/1 | 0 |
| 34+5| 2500   | NND           | CMP: cardiomegaly   | CMP: cardiomegaly | CMP: cardiomegaly | Hydropic, hydrothorax^a | 1/1 | 0 |
| 35+2| 2525   | IUFD          | CMP: Cardiomegaly, myocardial hypertrophy thick, solid foramen ovale | CMP: Cardiomegaly | CMP: cardiomegaly | Anhydramnios, mult. MF, pericardial effusion^b | 0/1 | 0 |
| 36+0| 1760   | Feticide      | normal              | VSD, TOF/DORV, overriding aorta | VSD, DORV, overriding aorta | Trisomy 18, mult. MF | 1/5 | 3 |
| 36+3| 2140   | NND           | TOF, VSD, PS        | DORV, PLSVC | TOF, PS, PLSVC, atretic DAB | Renal agenesis, anhydramnios | 0/3 | 0 |

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### SUPPLEMENTAL TABLE 2

Details of fetal cardiac MFs evaluated by prenatal ultrasound, 3Tesla postmortem magnetic resonance imaging, and autopsy (continued)

| GA   | BW (g) | Mode of death | Prenatal ultrasound | 3T pmMRI | Autopsy | Additional Anomaliesa | Interval death to pmMRI/autopsy (d) | Degree of maceration |
|------|--------|---------------|---------------------|----------|---------|-----------------------|-------------------------------------|---------------------|
| 36 + 4 | 1790 | NND | normal | VSD | normal | Skeletal dysplasia, mult. MF | 3/5 | 0 |
| 36 + 4 | 2930 | NND | ASD II | Normal | normal | Skeletal dysplasia, microthorax | 2/6 | 0 |
| 37 + 4 | 1651 | IUFD | ASD | normal | normal | Mult. MF | 1/4 | 2 |
| 37 + 5 | 2140 | NND | ND | Complex SV, ASD, VSD, Aorta from RV, hypoplastic PA | Complex SV, ASD, VSD, Aorta from RV, hypoplastic PA | Trisomy13, mult. MF | 0/2 | 0 |
| 38 + 1 | 3110 | NND | DORV | Aorta > PA | normal | Heterotaxy, DH (right) | 0/1 | 0 |

All cases that contained at least 1 abnormal cardiac finding in either imaging modality (prenatal ultrasound, cardiac 3Tesla postmortem magnetic resonance imaging) or at autopsy are included.

AIST, aortic isthmus stenosis; AoA, aortic arch; AS, aortic stenosis; ASD, atrial septal defect; AVSD, atrioventricular septal defect; CMP, cardiomyopathy; DAB, ductus arteriosus Botalli; DC, dichorionic; DH, diaphragmatic hernia; DORV, double-outlet right ventricle; d-TGA, d-transposition of the great arteries; FO, foramen ovale; HLHS, hypoplastic left heart syndrome; HRHS, hypoplastic right heart syndrome; IUFD, intrauterine fetal death; LA, left atrium; LV, left ventricle; MI, mitral valve insufficiency; mult., multiple; ND, nondiagnostic; NND, neonatal death; PA, pulmonary artery; PLSVC, persistent left superior vena cava; PS, pulmonary artery stenosis; PV, pulmonary valve; RA, right atrium; RV, right ventricle; SV, single ventricle; VSD, ventricular septal defect; TI, tricuspid valve insufficiency; TOF, tetralogy of Fallot; TOP, termination of pregnancy; TV, tricuspid valve.

a Fetuses with extracardiac or intrathoracic abnormalities.

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### SUPPLEMENTAL TABLE 3
Problems encountered at nondiagnostic and severely limited cardiac 3Tesla postmortem magnetic resonance imaging examinations, when autopsy was diagnostic

| GA (wk/d) | Weight (g) | D after death, mode of death | Maceration score | Body shape/additional MFs/limitations to 3T pmMRI | Genetic findings | Cardiac 3T pmMRI | Autopsy: cardiac findings |
|-----------|------------|-----------------------------|-----------------|-----------------------------------------------|-----------------|-----------------|--------------------------|
| 13+2      | 25 g       | 4 d after IUFD              | Score 2         | normal/NT 4.4 mm                              | Trisomy 18      | ND              | TOF                      |
| 14+1      | 28 g       | 4 d after TOP               | Score 0         | severe bilateral hydrothorax/NT 12 mm         | 45, XO          | ND              | CoA                      |
| 14+1      | 70 g       | 2 d after miscarriage       | Score 0         | severely deformed body                         | -               | ND              | normal                   |
| 14+2      | 22 g       | 4 d after TOP               | Score 0         | severe FGR                                     | Triploidy       | ND              | CoA                      |
| 14+4      | 44 g       | 2 d after TOP               | Score 0         | multiple severe extrathoracic MF              | -               | ND              | normal                   |
| 15+0      | 37 g       | 5 d after IUFD              | Score 2         | multiple severe extrathoracic MF              | Trisomy 18      | ND              | TOF                      |
| 15+0      | 70 g       | 3 d after TOP               | Score 1         | blurry images, epidermolysis bullosa          | abnormal        | ND              | normal                   |
| 15+2      | 50 g       | 4 d after TOP               | Score 0         | multiple intra- and extrathoracic MF          | -               | ND              | VSD                      |
| 15+5      | 72 g       | 1 d after TOP               | Score 0         | ventricles collapsed, left DH, mult. MF      | normal          | ND              | TOF                      |
| 15+6      | 79 g       | 5 d after TOP               | Score 2         | ventricles collapsed and crushed, multiple severe extrathoracic MF; limited diagnostic value | normal | limited | normal |
| 16+1      | 83 g       | 3 d after TOP               | Score 0         | ventricles collapsed and dislocated, masked anatomy, hydrops; limited diagnostic value | 45,X0 | limited | normal |
| 16+4      | 33 g       | 4 d after miscarriage       | Score 3         | deformed body shape                            | -               | ND              | normal                   |
| 16+5      | 42 g       | 6 d after IUFD              | Score 3         | deformed body shape                            | -               | ND              | normal                   |
| 17+1      | 72 g       | 5 d after IUFD              | Score 3         | spongy structures                              | -               | ND              | normal                   |
| 17+2      | 50 g       | 3 d after IUFD              | Score 3         | severely deformed body                         | -               | ND              | normal                   |
| 17+4      | 150 g      | 2 d after TOP               | Score 0         | compression of the heart owing to severe bilateral hydrothorax, hydrops | 45,X0 | ND | normal |
| 18+0      | 78 g       | 5 d after IUFD              | Score 3         | severely deformed body                         | -               | ND              | normal                   |
| 18+3      | 300 g      | 3 d after IUFD              | Score 3         | flat fetus after anhydramnios owing to bilateral polycystic-dysplastic kidneys | - | ND | normal |
| 18+4      | 83 g       | 3 d after IUFD              | Score 3         | severely deformed, autolytic body              | -               | ND              | normal                   |
| 18+4      | 264 g      | 4 d after miscarriage       | Score 0         | ventricles collapsed, ventricular septum nondiagnostic, exam limited | - | limited | normal |
| 20+3      | 320 g      | 5 d after IUFD              | Score 3         | deformed and autolytic body                   | -               | ND              | normal                   |
| 21+3      | 104 g      | 2 d after IUFD              | Score 3         | deformed thorax, wrong sequences for heart and vessels | - | ND | normal |
| 22+0      | 190 g      | 112 d after IUFD            | Score 3         | severely deformed body after laser ablation in monochorionic twin pregnancy | - | ND | normal |

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| GA (wk/d) | Weight (g) | D after death, mode of death | Maceration score | Body shape/additional MFs/limitations to 3T pmMRI | Genetic findings | Cardiac 3T pmMRI | Autopsy: cardiac findings |
|----------|-----------|-----------------------------|------------------|------------------------------------------------|----------------|-----------------|--------------------------|
| 22+5     | 510 g     | 2 d after TOP               | Score 0          | mechanic dislocation and compression of the heart owing to right-sided DH, exam limited | -              | limited         | normal                  |
| 24+4     | 264 g     | 4 d after IUFD              | Score 0          | severely deformed, crushed body, FGR              | -              | ND              | normal                  |
| 27+2     | 484 g     | 60 d after feticide         | Score 3          | severely deformed body after feticide in dichorionic twin pregnancy | -              | ND              | AVSD, ASD II            |
| 29+2     | 718 g     | 27 d after IUFD             | Score 3          | severely deformed body after cord clamping for hydrocephaly in monochorionic twin pregnancy | -              | ND              | normal                  |
| 31+2     | 1598 g    | 3 d after IUFD              | Score 2          | spongy imaging, exam limited                      | -              | ND              | normal                  |
| 32+6     | 1700 g    | 6 d after IUFD              | Score 3          | severely deformed body, spongy                    | Microarray     | ND              | normal                  |
| 38+0     | 3700 g    | 1 d after IUFD              | Score 3          | imaging, extrathoracic MF                         | -              | ND              | normal                  |

ASD, atrial septal defect; AVSD, atrioventricular septal defect; CoA, coarctation of the aorta; DH, diaphragmatic hernia; FGR, fetal growth restriction; GA, gestational age (weeks, days); IUFD, intrauterine fetal death; MF, malformations; NT, nuchal translucency; TOF, tetralogy of Fallot; TOP, termination of pregnancy; VSD, ventricular septal defect.

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