

Alma Mater Studiorum Università di Bologna
Archivio istituzionale della ricerca

Ultrasound diagnosis of placental and umbilical cord anomalies in singleton pregnancies resulting from in-vitro fertilization

This is the final peer-reviewed author's accepted manuscript (postprint) of the following publication:

Published Version:

Larcher, L., Jauniaux, E., Lenzi, J., Ragnedda, R., Morano, D., Valeriani, M., et al. (2023). Ultrasound diagnosis of placental and umbilical cord anomalies in singleton pregnancies resulting from in-vitro fertilization. *PLACENTA*, 131, 58-64 [10.1016/j.placenta.2022.11.010].

Availability:

This version is available at: <https://hdl.handle.net/11585/909498> since: 2022-12-12

Published:

DOI: <http://doi.org/10.1016/j.placenta.2022.11.010>

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This is the accepted manuscript of:

Larcher L, Jauniaux E, Lenzi J, Ragnedda R, Morano D, Valeriani M, Michelli G, Farina A, Contro E.

Ultrasound diagnosis of placental and umbilical cord anomalies in singleton pregnancies resulting from in-vitro fertilization.

Placenta. 2023 Jan;131:58-64.

The final published version is available online at: <https://doi.org/10.1016/j.placenta.2022.11.010>

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1 **ULTRASOUND DIAGNOSIS OF PLACENTAL AND UMBILICAL** 2 **CORD ANOMALIES IN SINGLETON PREGNANCIES RESULTING** 3 **FROM IN-VITRO FERTILIZATION**

4

5 Larcher L., Lenzi J., Morano D., Valeriani M., Michelli G., Farina A., Contro E.

6

7 **INTRODUCTION**

8 From the birth of the first IVF baby on the 25th of July 1978, the association between fertility
9 treatments and pregnancy complications have remained the topic of heated debates¹.

10 Overall, four decades of epidemiologic studies have shown that pregnancies resulting from
11 assisted reproductive technology (ART) are at higher risk than spontaneous conceptions
12 (SC) for adverse perinatal outcomes, including perinatal mortality, preterm birth, low birth
13 weight and birth defects²⁻⁸. These risks are partly attributable to infertility characteristics,
14 ART methods, embryo freezing, intracytoplasmic sperm injection (ICSI), maternal age and
15 twinning^{5,6}.

16 ICSI, which was first introduced as an adjunct to IVF in the early 1990s⁹, has been
17 associated with controversial findings regarding the risk of birth defects. An early study found
18 no significant additional risks of major birth defects in pregnancies conceived with this
19 technique compared to standard IVF¹⁰ but recent systematic reviews have shown that, after
20 adjustment for confounding factors, IVF (with or without ICSI) increases the risk of congenital
21 heart defects, when compared with SC^{5,8}. By contrast, no increased risk of congenital
22 anomalies has been demonstrated after fresh versus frozen embryo transfer, IVF vs ICSI¹¹
23 or after preimplantation genetic testing¹².

24 The use of ART has also been associated with an increased risk of disorder of
25 placentation including placenta previa^{2,12-18}, umbilical cord anomalies¹⁹⁻²¹ and, more
recently, placenta accreta spectrum (PAS)¹⁹⁻²¹. The risk of placenta previa in singleton
pregnancies was recently found to be higher after fresh blastocyst transfer compared to

26 fresh cleavage stage transfer or SC¹⁷. A recent systematic review has shown that natural
27 cycle frozen embryo transfer in singleton pregnancies conceived after IVF decreased the
28 risk of PAS compared with artificial cycle frozen embryo transfer²². There are limited data
29 on the impact of heterologous fertilization using donor oocytes on placentation^{23–25}.

30 Most studies on the association of IVF with placental/cord anomalies are
31 retrospective and small, or included in large epidemiologic studies with multiple confounding
32 factors and none have studied the role of prenatal ultrasound imaging in IVF pregnancies.
29 Placental and umbilical cord anomalies can have an impact on both fetal and maternal
30 outcomes due to severe maternal haemorrhage, potentially requiring emergency
31 hysterectomy, and cord accidents that can lead to severe fetal neurological damage and/or
32 intrapartum demise. The aims of the present study are: to determine the incidence of
33 placental and cord anomalies in singleton IVF pregnancies compared to spontaneous
34 pregnancies; to prospectively evaluate the role of antenatal ultrasound in the screening for
35 these anomalies and to investigate if oocyte donor fertilization is an additional risk factor for
36 the development of placentation anomalies.

37

38 **METHODS**

39 This was a multicenter prospective cohort study involving two tertiary centers (Sant'Orsola
40 Hospital, University of Bologna and Institute for Women's Health and University College of
41 London). Patients with a singleton pregnancy conceived with IVF and patients with a SC
42 (controls), matched with a 1:1 ratio for the number of prior cesarean deliveries (CDs), were
43 consecutively recruited between 1st May 2019 to 31st March 2021. Random matches were
44 performed by generating pseudorandom-number functions using Stata 15, and unmatched
45 spontaneous pregnancies were discarded from the analysis. IVF pregnancies were defined
46 homologous or heterologous in base of the oocyte. Homologous if the oocyte is obtained
47 from the women, heterologous if the oocyte is donated from another women.

48 All patients received antenatal care using a similar clinical protocol, which included
49 ultrasound examinations at 11-14 weeks (nuchal translucency scan), 19-22 weeks (detailed
50 fetal anatomy scan) and 32-35 weeks (fetal wellbeing and growth scan). All ultrasound
51 examinations were carried out transvaginally and/or transabdominally by experienced

52 operators using a high-resolution ultrasound equipment (GE Voluson[®] E10, Voluson 730
53 and E8 Expert, GE Medical Systems, Milwaukee, WI, USA). Ultrasound findings of placental
54 and/or umbilical cord abnormalities were recorded in each case using a standardized
55 reporting protocol including placental shape, placental location, cord insertion location and
56 number of cord vessels. We defined a placenta as “low lying” if the inferior edge was located
57 at 0.5-2 cm from the internal os of the uterine cervix. When the placenta was <0.5cm from
58 the internal os, or completely covering it, it was classified as placenta previa (marginal or
59 complete)²⁶. Ultrasound signs of PAS were recorded using the standardized description
60 proposed by the European Working Group on Abnormally Invasive Placenta EW-AIP²⁷
61 including for grey scale imaging: loss of clear zone, myometrial thinning, the presence of
62 placental lacunae; bladder wall interruption; placental bulge and focal exophytic mass and
63 for CDI: utero-vesical hypervascularity; subplacental hypervascularity; bridging vessels and
64 lacunae feeder vessels. Additional transabdominal and transvaginal sonographic (TVS)
65 examinations of the placental location and cord insertion were performed at 28-30 weeks
66 and 36-37 weeks when required for the timing of delivery (Figures 1 and 2).

67 Women unmatched by prior CD, or requiring emergency delivery before 32 weeks
68 ultrasound examination, were excluded from the study (Supplementary Figure S1). When a
69 patient in either subgroup was excluded from the study, her match in the ~~spontaneous~~
70 control group was excluded from the final analysis (Supplementary Figure S1). All patients
71 were managed according to local protocols. Patients’ demographic data, previous obstetric
72 and gynecological history, clinical findings, ultrasound data/images and symptoms at the
73 time of the first examination were recorded and stored in a specialized database (Viewpoint
74 Version 5, Bildverargeritung GmbH, Munich, Germany). All placentas and umbilical cords in
75 both groups were examined macroscopically at delivery by the obstetric team and the
76 findings recorded using a standard protocol. Full histopathological evaluation was carried
77 out when clinically indicated.

78 Institutional ethical committee approval was obtained prior to the start of this study,
79 UK NHS Health Research Authority (HRA). Research Ethical committee approval reference
80 18/WM/0328. The protocol and a waiver of consent were granted a favorable opinion as all
81 ultrasound records were examined within the center and basic clinical data were collected
82 using a standard clinical audit protocol and all data and images were fully anonymized for
83 further analysis.

84 **Sample size determination**

85 Assuming that the proportion of placental or cord anomalies was 0.20 in spontaneous
86 pregnancies and 0.30 in pregnancies conceived with heterologous or autologous IVF^{13,28}, a
87 total sample of 588 individuals (294 per group) had to be obtained to detect an absolute
88 difference of 0.10 between the two proportions with 80% power and 5% significance level.
89 Hypothesizing an attrition rate of 7%, the final sample size was augmented from 588 to 634
90 (317 per group).

91 **Statistical analysis**

92 Stata 15 (StataCorp. 2017. *Stata Statistical Software: Release 15*. College Station, TX:
93 StataCorp LP) and R version 4.1.0 (R Core Team. 2021. *R: A language and environment
94 for statistical computing*. Vienna, Austria: R Foundation for Statistical Computing) were used
95 to analyze the data. Q–Q plot analysis confirmed the normal distribution of continuous
96 variables, and data are therefore presented as mean and standard deviation. Categorical
97 variables are presented as counts and percentages.

98 Univariate comparisons of demographic and clinical characteristics between IVF and
99 spontaneous pregnancies were performed with the Pearson's chi-squared test, Fisher's
100 exact test or Student's *t*-test, where appropriate. Differences in the rate of placental and cord
101 anomalies in the study groups (IVF versus spontaneous pregnancies) and subgroups
102 (heterologous versus homologous) were calculated using the chi-squared test or Fisher's

103 exact test, where appropriate. Post-hoc pairwise comparisons were performed with the
104 Fisher's exact test, using the Simes' method for false discovery rate control²⁹.

105 The multivariable (adjusted) association between patient characteristics (mode of
106 conception, maternal age, prior CD, parity and gravidity) and specific ultrasound findings
107 (low-lying/placenta previa and velamentous cord insertion) was estimated with a logistic
108 regression model using Firth's method, a technique equivalent to penalization of the log-
109 likelihood by the Jeffreys prior that reduces the bias of maximum likelihood estimates and
110 represents a solution to the problem of separation and rare events. Results are presented
111 as odds ratios (OR) and 95% Confidence intervals (CI). *P* values to test their significance
112 were computed by penalized profile likelihood³⁰. A *P* value <0.05 was considered significant.

113

114 **RESULTS**

115 ***Cohort demographics***

116 There were 654 singleton pregnancies assessed for eligibility during the study period. After
117 exclusion of prior-CD unmatched pregnancies and GAs at delivery <32 weeks, a total of 317
118 pregnancies resulting from IVF were enrolled in the study, including 6 (1.9%) with a history
119 of two prior CDs, 32 (10.1%) with a history of one prior CD, and 279 (87.7%) nulliparous or
120 primiparous/multiparous with a prior vaginal birth (Supplementary Figure S1). Of these 317
121 pregnancies, 237 (74.8%) resulted from autologous oocyte IVF cycles and 80 (25.2%) from
122 heterologous (oocyte donor) IVF cycles. The SC group was constituted by 317 spontaneous
123 pregnancies, including 6 (1.9%) with a history of two prior CDs, 32 (10.1%) with one prior
124 CD, and 279 (87.7%) nulliparous or with prior vaginal. Table 1 displays and compares the
125 demographic and clinical characteristics of the study groups. Maternal age was significantly
126 (*P*<0.001) higher in patients with IVF pregnancies than those with spontaneous
127 pregnancies. There were significantly more patients of Caucasian ethnicity, nulliparous and
128 primigravid in the IVF pregnancy group than in the SC group. There were no differences in

129 body mass index (BMI) and smoking status between the groups.

130 **Ultrasound findings**

131 All patients with placenta and umbilical cord anomalies were identified at the 20-22 weeks
132 ultrasound examination and confirmed at the 33-35 weeks scan and at birth (Figures 1-3).
133 Except for the examinations of the placental location and cord insertion that were performed
134 at 28-30 week and 36-37 weeks when required for the timing of delivery. There were two
135 cases of placenta previa with ultrasound signs suggesting accreta placentation in the
136 heterologous IVF subgroups. Both patients had an elective cesarean section with abnormal
137 attachment of part the placenta into the scar area of prior lower segment of prior CD. Partial
138 myometrial resection was required and these cases were classified placenta adherenta.
139 There was no case of vasa previa in either subgroup.

140 Table 2 shows the distribution of the different anomalies of the placenta and umbilical
141 cord in both groups and between the heterologous and autologous IVF subgroups (all
142 combinations of placental and/or umbilical cord anomalies observed in the study sample are
143 showed in Supplementary Table S1). The overall incidence of combined placental and cord
144 anomalies was significantly higher in the IVF group than in the SC group (97 [30.6%] vs 62
145 [19.6%]; $P<0.001$). A significantly higher incidence of low-lying placenta ($P<0.001$), placenta
146 previa ($P=0.012$), bilobed placenta ($P<0.001$) and velamentous cord insertion (VCI)
147 ($P=0.001$) was found the IVF compared to the SC group. There was no difference between
148 the two groups for the incidence of marginal cord insertion and single umbilical artery cord.
149 The incidence of placenta previa accreta was significantly higher ($P=0.016$) in heterologous
150 IVF pregnancies compared with homologous and spontaneous pregnancies.

151 Number of prior CDs was a significant ($P=0.014$) risk factor for the development of
152 placenta previa in the whole cohort (Supplementary Table S2).

153 The results of the multivariable logistic regression analysis are presented in Table 3.
154 After adjusting for maternal age, prior CDs, parity and gravidity, IVF conception remained a

155 significant ($P<0.001$) risk factor for low-lying/placenta and autologous IVF conception for
156 VCI ($P=0.037$). The OR (95% CI) for low-lying/placenta previa and VCI was 9.99 (CI 2.84–
157 53.25) and 5.44 (CI 1.10–53.82), and 18.58 (CI 3.53–129.68) and 7.44 (CI 0.96–96.73) in
158 the autologous and heterologous IVF subgroup, respectively.

159

160 **DISCUSSION**

161 Our data add to previous epidemiologic studies showing that IVF conceptions are
162 associated with a higher incidence of placental and cord implantation anomalies and
163 indicate that these anomalies are independent of a history of prior CD and can be accurately
164 identify before birth using standardized ultrasound imaging protocols allowing for individual
165 patient management and thus reducing the corresponding maternal and fetal mortality and
166 morbidity risks.

167

168 ***Comparison with other studies***

169 Romundstad et al¹³ were the first to report on the risk of placenta previa in singleton
170 pregnancies conceived by ART. This nationwide population-based study, and more recent
171 studies^{15,16} found that the risk of placenta previa was nearly three-fold higher in ART
172 pregnancies compared with SP. Most of epidemiologic studies do not provide data on the
173 type of ART technique used for conception or mode of delivery and none describe the
174 ultrasound criteria used for the diagnosis of placenta previa. A prior CD is the main
175 independent confounding factor for placentation in the lower segment in subsequent
176 pregnancies¹⁸. After exclusion of a prior CD and other independent risk factors such as
177 multiple pregnancies for low placentation, our data confirms that a low-lying placenta is the
178 most common placenta anomaly associated with IVF (Table 2). The multivariable logistic
179 regression analysis indicated higher OR for low placental insertion in the heterologous than

180 in the autologous IVF subgroup (Table 3), suggesting an impact of the IVF technique on
181 placentation.

182 There is a strong correlation between the shape of the placenta at the end of the first
183 trimester and that at term³¹, suggesting that events during the first trimester are critical.
184 There is limited evidence on an association between IVF and anomalies of the placental
185 shape. A retrospective study of 47 cases of succenturiate lobes of the placenta found an
186 association with IVF³². A recent study of 1057 live births following IVF treatment found that
187 after adjustment for potential confounding factors associated with placental pathology
188 features, female gender was associated with bilobed placenta³³. In the present study, the
189 incidence of bilobed placenta was 3.8% (Table 2) in the IVF group, with a similar incidence
190 in the heterologous and autologous IVF subgroups; no case was found in the SC group.

191 In our study, two patients with placenta previa in the heterologous subgroups were
192 classified as high-risk of PAS at ultrasound and confirmed as having an abnormally adherent
193 placenta accreta (stage I of the FIGO classification)³⁴ at CS. Uncomplicated term ART
194 pregnancies have a higher risk of operative delivery, retained placenta and PPH¹⁴. IVF has
195 also been associated with the subsequent development of accreta placentation, but the
196 association is indirect and mainly due to the increase rate of low placentation following
197 embryo transfer^{18,19,35}. Heterogeneity in results is due to variation in the ultrasound criteria
198 used for the diagnosis of placenta previa and the lack of detailed confirmation of the accreta
199 grade at birth³⁶. Further studies are therefore required to confirm the association between
200 ART and PAS.

201 VCI and marginal cord insertion are found in approximately 1.5% and 6% of singleton
202 births and their incidence is increased with other risk factors, including twinning, IVF,
203 advanced maternal age³⁷. In the present study, a VCI was the only umbilical cord anomaly
204 found with a higher incidence in the IVF pregnancy group (3.8%) compared to 0.3% in the
205 SC group, but no difference was found for the incidence of marginal cord insertion between

206 the two groups (Table 2). The OR for VCI was higher in the autologous than in heterologous
207 subgroup (Table 3) suggesting an impact of the IVF technique on the blastocyst rotation at
208 implantation^{18,19}.

209

210 ***Clinical implications***

211 Reporting on the placental position has been an integral part of the detailed anomaly scan
212 in most countries around the world for at least three decades^{38,39}. Anyway, none of the
213 previous studies on the association between ART and placenta previa provided data on the
214 ultrasound method used, the gestational age at diagnosis or postnatal confirmation of
215 placental abnormalities¹³⁻¹⁷. All the patients in our study had the diagnosis of low-lying
216 placenta by TVS at 32-35 weeks.

217 VCI is associated with adverse perinatal outcomes, mainly premature rupture of the
218 membranes, spontaneous pre-term birth, short cord and risk of need for manual removal of
219 the placenta^{40,41}. Around 3-4% of women with VCI also have vasa previa⁴²; when this
220 condition is diagnosed during labor, the perinatal death rate is reported as at least 60%⁴³. A
221 recent prospective population-based cohort Australian study using the found that out of 63
222 cases with confirmed vasa previa at birth, there were no perinatal deaths in the 58 cases
223 diagnosed prenatally⁴⁴. These data support the need to include the location of the cord
224 insertion at the routine mid-trimester ultrasound examination. None of the patients with a
225 VCI in our study presented with vasa previa at the 32-35 weeks and were allowed to deliver
226 at term.

227

228 ***Strengths and Limitations***

229 Our study has several strengths. To the best of our knowledge, this is the largest prospective
230 study addressing the prenatal diagnosis of placental and cord anomalies in IVF pregnancies.
231 This is also the first study where IVF and spontaneous pregnancies were matched for a

232 history of prior CD and which compares the data from heterologous and autologous IVF
233 pregnancies. Our study has the same limitation as any study performed in specialist centers
234 and thus our data may not be representative of the general population. In addition, we did
235 not have access to data on embryo freezing and/or the use of ICSI in all cases, which may
236 both have an impact on placentation. Our analysis was not powered to detect significant
237 differences in the proportions of single placental or umbilical cord anomalies, nor between
238 heterologous vs autologous pregnancies.

239

240 **Conclusions**

241 IVF, in particular IVF with oocyte-donor cycle, is associated with an increased risk of
242 placentation and cord implantation anomalies. Ultrasound has a high diagnostic accuracy in
243 detecting these anomalies prenatally. Adequately powered studies for different IVF
244 techniques including frozen embryos and ICSI cycles are needed to accurately evaluate the
245 risks of abnormal placentation and develop standardized ultrasound screening strategies
246 targeted at high-risk patients.

247

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381

382 **Table 1.** Demographic and clinical characteristics of the study groups.

Variable	Mode of conception		P
	IVF (n = 317)	SC (n = 317)	
Maternal age, y	38.4 (5.5)	33.5 (5.2)	<0.001
BMI, kg/m ²	22.7 (3.5)	23.0 (4.2)	0.384
Ethnicity			
Caucasian	297 (93.7%)	266 (83.9%)	
African	3 (0.9%)	24 (7.6%)	
Asian	11 (3.5%)	16 (5.0%)	
Hispanic	3 (0.9%)	6 (1.9%)	
South Asian	3 (0.9%)	5 (1.6%)	<0.001
Smoking	17 (5.4%)	21 (6.6%)	0.503
Parity			
0	239 (75.4%)	171 (53.9%)	
1	64 (20.2%)	103 (32.5%)	
≥2	14 (4.4%)	43 (13.6%)	<0.001
Gravidity			
1	146 (46.1%)	120 (37.9%)	
≥2	171 (53.9%)	197 (62.1%)	0.036
Number of prior CDs			
0	279 (88.0%)	279 (88.0%)	
1	32 (10.1%)	32 (10.1%)	
2	6 (1.9%)	6 (1.9%)	1.000

383 *Note:* Values are presented as mean (SD) or n (%).

384 *IVF= In-vitro fertilization; SC= Spontaneous conception; CD= caesarean delivery; BMI= Body mass*

385 *index.*

386

387 **Table 2.** Distribution of placental and cord anomalies in the heterologous and autologous
 388 IVF pregnancies and in spontaneous pregnancies.

Placental/cord anomalies	Mode of conception			P value
	Heterologous IVF (n = 80)	Autologous IVF (n = 237)	SC (n = 317)	
<u>Number of patients with anomalies</u>	32 (40.0%)	65 (27.4%)	62 (19.6%)	<0.001
<u>Placental anomalies</u>	13 (16.3%) ^a	21 (8.9%) ^a	2 (0.6%)	<0.001
Low-lying placenta	4 (5.0%) ^a	9 (3.8%) ^a	0 (0.0%)	<0.001
Placenta previa	4 (5.0%) ^a	7 (3.0%) ^a	2 (0.6%)	0.012
Bilobed placenta	5 (6.3%) ^a	7 (3.0%) ^a	0 (0.0%)	<0.001
Placenta previa accreta	2 (2.5%) ^a	0 (0.0%) ^{a,b}	0 (0.0%) ^b	0.016
<u>Cord anomalies</u>	25 (31.3%) ^{a,b}	54 (22.8%) ^{a,c}	60 (18.9%) ^{b,c}	0.057
Marginal cord insertion	20 (25.0%) ^{a,b}	47 (19.8%) ^{a,c}	55 (17.4%) ^{b,c}	0.288
VCI	5 (6.3%) ^a	7 (3.0%) ^a	1 (0.3%)	0.001
Single umbilical artery	1 (1.3%) ^{a,b}	1 (0.4%) ^{a,c}	5 (1.6%) ^{b,c}	0.410

389
 390 *Including 8, 10 and 1 patient with ≥ 2 combined anomalies in the heterologous, autologous and SC
 391 subgroups, respectively.

392 *Note:* Categories denoted with the same letter are not significantly different from each other (post-
 393 hoc pairwise comparison).

394 *IVF= In-vitro fertilization; SC= Spontaneous conception; VCI= Velamentous cord insertion.*

395 **Table 3.** Multivariable logistic regression of risk factors for low-lying/placenta previa and
 396 velamentous cord insertion.

Variable	Low-lying/placenta previa		Velamentous cord insertion	
	OR (95% CI)	<i>P</i> value	OR (95% CI)	<i>P</i> value
<u>Mode of conception</u>				
SC	1.00 (ref.)		1.00 (ref.)	
Autologous IVF	9.99 (2.84–53.25)	<0.001	5.44 (1.10–53.82)	0.037
Heterologous IVF	18.58 (3.53–129.68)*	<0.001	7.44 (0.96–96.73)†	0.059
Maternal age, 1-y increase	1.003 (0.92–1.10)	0.932	1.06 (0.94–1.21)	0.349
Number of prior CDs				
0	1.00 (ref.)		1.00 (ref.)	
1	3.25 (0.85–14.01)	0.086	0.72 (0.06–5.53)	0.756
2	2.43 (0.27–22.50)	0.417	1.15 (0.01–233.79)	0.948
Parity				
0	1.00 (ref.)		1.00 (ref.)	
1	1.06 (0.22–4.37)	0.938	1.32 (0.21–6.34)	0.743
≥2	3.45 (0.49–18.87)	0.194	1.05 (0.01–12.54)	0.974
Gravidity				
1	1.00 (ref.)		1.00 (ref.)	
≥2	0.92 (0.29–2.70)	0.876	1.16 (0.31–4.39)	0.819

397 *OR (95% CI) = 1.86 (0.61–5.41) when autologous IVF is used as the reference group (*P* = 0.264).

398 †OR (95% CI) = 1.37 (0.31–5.58) when autologous IVF is used as the reference group (*P* = 0.668).

399 OR= odds ratio; CI= confidence interval; SC= Spontaneous conception; IVF= In-vitro fertilization;
 400 CD= caesarean delivery.