



**HAL**  
open science

## **New insights in cerebral findings associated with fetal myelomeningocele: a retrospective cohort study in a single tertiary centre**

P Maurice, J Garel, C Garel, F Dhombres, S Friszer, L Guilbaud, E Maisonneuve, H Ducou Le Pointe, E Blondiaux, J-M Jouannic

### ► **To cite this version:**

P Maurice, J Garel, C Garel, F Dhombres, S Friszer, et al.. New insights in cerebral findings associated with fetal myelomeningocele: a retrospective cohort study in a single tertiary centre. *BJOG: An International Journal of Obstetrics and Gynaecology*, 2021, 128 (2), pp.376-383. 10.1111/1471-0528.16185 . hal-03263489

**HAL Id: hal-03263489**

**<https://hal.sorbonne-universite.fr/hal-03263489v1>**

Submitted on 17 Jun 2021

**HAL** is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

1 **New insights in cerebral findings associated with fetal myelomeningocele: a**  
2 **retrospective cohort study in a single tertiary centre**

3  
4 Maurice P<sup>1, 2</sup>, Garel J<sup>3</sup>, Garel C<sup>3</sup>, Dhombres F<sup>1,2</sup>, Friszer S<sup>1,2</sup>, **Guilbaud L<sup>1,2</sup>**,  
5 Maisonneuve E<sup>1,2</sup>, Ducou Le Pointe H<sup>3</sup>, Blondiaux E<sup>3</sup>, Jouannic JM<sup>1,2</sup>

6 <sup>1</sup>Service de Médecine Foetale, Centre de Référence Maladie Rares MAVEM, Hôpital  
7 Armand Trousseau, Médecine Sorbonne Université, APHP, Paris, France

8 **<sup>2</sup>Reference Center for Rare Disease: vertebral and spinal cord anomalies,**  
9 **Trousseau, France**

10 <sup>3</sup>Service de Radiopédiatrie, Hôpital Armand Trousseau, Médecine Sorbonne Université,  
11 APHP, Paris, France

12 Corresponding author: Jean-Marie Jouannic, Service de Médecine Foetale, Hôpital  
13 Armand Trousseau, 26 avenue Arnold Netter, 75012 Paris, France

14 Tel : +33 171 735 228

15 Email: [jean-marie.jouannic@aphp.fr](mailto:jean-marie.jouannic@aphp.fr)

16

17 Shortened running Tittle: fetal cerebral anomalies associated with MMC

18

19

20

21

22 **Abstract**

23 **Objective:** to investigate cerebral anomalies other than Chiari type 2 malformation  
24 in fetuses with myelomeningocele.

25 **Design:** A retrospective cohort study in a single tertiary centre.

26 **Setting:** a review of associated cerebral anomalies in cases with prenatal diagnosis of  
27 myelomeningocele.

28 **Population:** 70 cases of foetal myelomeningocele.

29 **Methods:** Ultrasound and MRI images were blindly reviewed. Postnatal imaging and  
30 results of the **post-mortem results were also reviewed. The association between**  
31 **cerebral anomalies and the following US findings was measured: level of the**  
32 **defect, ventriculomegaly, microcephaly and foetal talipes.**

33 **Main outcome measures:** A microcephaly was observed in 32/70 cases (46%), a  
34 ventriculomegaly was observed in 39/70 cases (56%). Other cerebral anomalies  
35 were diagnosed in 47/70 (67%).

36 **Results :** Other cerebral anomalies were represented by 42/70 cases with  
37 abnormal CC (60%), 8/70 cases with PNH (11%), 2/70 cases with abnormal gyration  
38 (3%). MRI only performed in foetal surgery cases confirmed US findings in all  
39 cases, and provided additional findings in 2 cases (PNH). Risk ratios of foetal  
40 cerebral anomalies associated with MMC did not reach significance for  
41 microcephaly, ventriculomegaly, talipes and for the level of the defect There was  
42 an overall good correlation between pre and postnatal findings with a Kappa value of  
43 0.79 [0.57-1]<sub>CI95%</sub> and a proportion of agreement of 82%.

44 **Conclusion:** foetal brain anomalies other than Chiari type 2 malformation, are  
45 frequently observed in fetuses with myelomeningocele, predominantly

46 **represented by CC anomalies. Whether these associated cerebral anomalies**  
47 **should have an impact on selecting cases eligible for fetal surgery needs further**  
48 **evaluation.**

49 **Funding statement: This study was funded by a grant from the Programme**  
50 **Hospitalier de Recherche Clinique – PHRC 2013 (French Ministry of Health) and**  
51 **was promoted by La Délégation à la Recherche Clinique et l'Innovation de l'AP-**  
52 **HP (Assistance Publique-Hôpitaux de Paris).**

53  
54 **Key-words:** myelomeningocele, prenatal diagnosis, ultrasound, cerebral anomalies,  
55 corpus callosum

56  
57 **Tweetable abstract:** foetal cerebral anomalies other than Chiari type 2 malformation,  
58 microcephaly and ventriculomegaly may be associated with MMC in up to 67% of the  
59 cases.

60

61 **Introduction**

62 Myelomeningocele (MMC) represents a specific form of neural tube defect with  
63 an incidence of approximatively 3-4 per **10.000** live births in Europe<sup>1</sup>. **The exposure of**  
64 **the non-neurulated spinal cord and nerve roots to external environment is**  
65 **responsible for motor dysfunction** (weakness or paralysis) and for both bowel and  
66 bladder dysfunction<sup>2</sup>. **In addition, there are specific brain anomalies associated with**  
67 **this defect, most commonly Chiari type 2 malformation and frequent associated**  
68 **ventriculomegaly and microcephaly<sup>3</sup>.**

69 In neonates undergoing surgical repair of myelomeningocele, a wide spectrum in  
70 terms of size, shape, level of defect and appearance of cerebral structures is observed  
71 (the posterior fossa structures, the corpus callosum and the cerebral cortex)<sup>3,4</sup>. Chiari  
72 type 2 malformation is observed in almost all cases of MMC<sup>4,5</sup>. **Hydrocephalus is**  
73 **frequently seen, being present in about half of the patients with MMC<sup>3</sup>.** Corpus  
74 callosum (CC) anomalies are also frequent in cohorts of adult patients, with  
75 controversies on the underlying mechanism leading to these anomalies, as they are  
76 often associated with hydrocephalus in these patients<sup>3,6,7</sup>.

77 There is no available data on the incidence of corpus callosum and cortex  
78 abnormalities in foetuses with MMC. **In the setting of foetal surgery, these data are of**  
79 **utmost importance since prenatal repair is theoretically reserved for foetuses**  
80 **presenting with MMC with no other anomaly than Chiari type 2 malformation,**  
81 **ventriculomegaly, microcephaly or talipes.**

82 We aimed to retrospectively review all cases of MMC referred to our centre and  
83 for **which** complete ultrasound examinations of the foetal brain performed by an

84 experienced sonographer were reviewed by two independent operators blinded to the  
85 perinatal outcome.

86

## 87 **Material and Methods**

88 **This was a retrospective study of 70 cases of fetuses with MMC** examined  
89 between November 2013 and February 2019 in the setting of the PRIUM study<sup>8</sup>: French  
90 study on prenatal repair of foetal myelomeningoceles using open surgery technique<sup>9</sup>  
91 (Clinical Trial registration NCT01983345; Institutional Review Board approval 13048).

92 **There was no patient and public involvement.** Patients with suspicion of foetal MMC  
93 were referred to our centre. **As part of our usual plan of care, all cases are evaluated**  
94 **by a second line US examination performed by one experienced operator (CG).**  
95 **Additional MRI examination is offered either systematically in case of foetal**  
96 **surgery, or when additional anomalies are suspected at ultrasound examination.**  
97 **In our centre there is no policy of systematic fetal MRI in case of typical MMC at**  
98 **second line US examination.**

99 The second line ultrasound (US) was performed by an experienced operator  
100 using a Aplio 400 unit (Canon Medical Systems, Otawara, Japan) with vector and  
101 curved-array transducers and magnified images focused on the spine and spinal cord  
102 utilizing high frequency (8-15 MHz) linear array transducers. When abdominal route was  
103 not sufficient for detailed examination of the foetal brain, and depending on the foetal  
104 position, a vaginal examination was performed using high frequency vaginal probes. An  
105 entire examination of the foetal brain, including examination of the CC was performed.  
106 **The fetal MRI examinations were performed using a 1.5 Tesla Unit (Achieva;**

107 **Philips Medical Systems, Best, The Netherlands from 2013 to 2015 and Optima**  
108 **MR450w; General Electric (GE), Waukesha, WI since 2016). SSFSE sequences**  
109 **were acquired for all fetuses in three orthogonal spaces. In order to reduce**  
110 **motion artefacts, maternal sedation was systematically offered. 2D images in the**  
111 **three planes of the space were repeated until the quality was deemed good.**

112 The gestational age at diagnosis of MMC was recorded. When several US scans  
113 were performed, results of the first complete evaluation, the nearest to the diagnosis,  
114 were taken into account. **The level of the MMC defect was classified as low when**  
115 **the uppermost vertebral defect was below L3 or as high when it was L3 or higher.**  
116 **Regarding the fetal brain, the US parameters recorded were (1) microcephaly**  
117 **defined by head circumference < 3<sup>rd</sup> centile<sup>10</sup>, (2) presence or absence of**  
118 **ventriculomegaly defined by a diameter of the ventricular atrium measured on the**  
119 **axial view  $\geq 10$  mm, (3) anomalies of the CC and (4) associated parenchymal**  
120 **anomalies represented by subependymal heterotopia or gyration disorders.**  
121 Anomalies of the CC included absent, short, thick or apparently normal but stretched  
122 CC. **The CC was defined as short when length measurement was < 3<sup>rd</sup> centile**  
123 **using reference curves by Cignini et al.<sup>11</sup>. A short CC was then classified as**  
124 **complete (figure 1) or incomplete (figure 2); when incomplete, the missing part**  
125 **was noted (rostrum, genu, body, splenium). A CC was defined as thick when  $\geq 3$**   
126 **mm at the mid-coronal plane as described by Achiron et al. <sup>12</sup>. Extra-cranial**  
127 **anomalies and the presence of foetal talipes were also recorded.**

128 Parents were offered prenatal counselling involving a specialist in foetal medicine  
129 and a paediatric neurosurgeon, with information on the prognosis of the anomaly and

130 the benefice-risk balance of prenatal versus postnatal repair. **Foetal karyotype**  
131 **analysis was offered in all cases.** According to the French law, termination of  
132 pregnancy (TOP) was possible at parental request **irrespective of gestational age.**  
133 All cases of confirmed diagnosis of MMC were included. Cases associated with  
134 chromosomal anomalies or polymalformative syndromes were excluded. We also  
135 excluded cases for which termination of pregnancy (TOP) was performed before 20  
136 weeks of gestational age (GA) since corpus callosum anatomy could not be evaluated.

137 Results of the post-mortem (PM) examination were recorded when accepted by  
138 the parents in cases of TOP. **The PM examination protocol included a two-month**  
139 **period of formalin fixation of the foetal brain to allow anatomical examination of**  
140 **the foetal brain structures. As part of our usual plan of care in liveborn neonates,**  
141 **transfontanellar US examination is systematically performed during the first week**  
142 **of life and cerebral MRI examination is systematically performed during the first 3**  
143 **months of life regardless of the timing of the surgery.**

144 Both prenatal and postnatal imaging (head US and/or brain MRI) were reviewed  
145 blind to the perinatal outcome by the same team (PM and JG). Cerebral anomalies were  
146 **analysed** as described above. **For the CC postnatal imaging, the following features**  
147 **were recorded: (1) length of the corpus callosum, considered as short when**  
148 **inferior to the 3<sup>rd</sup> centile according to C. Garel curve<sup>13</sup> (2) objective thickness of the**  
149 corpus callosum measured at the level of the genu, body, and splenium, and considered  
150 thickened when one of the measurement was superior to the 97<sup>th</sup> percentile<sup>13</sup>.

151

152 Statistical analysis.



153 Statistical analysis was performed using R, version 3.3.1 (R Foundation for  
154 Statistical Computing, Vienna, Austria) and STATA, version 15 (StataCorp, College  
155 Station, Texas, USA). **The association between cerebral anomalies and the**  
156 **following US findings was measured by computing Risk Ratios (RR) and 95%**  
157 **confidence intervals: level of the defect, ventriculomegaly, microcephaly and**  
158 **foetal talipes.** The relationship between decision of TOP and cerebral anomalies was  
159 tested by Odds Ratio (OR), and a P value < 0.05 was considered statistically significant.  
160 Adjusted kappa coefficients (Cohen weighted kappa) for CC categories (normal,  
161 stretched, short and absent) were computed to test for the agreement between prenatal  
162 and postnatal findings. Adjusted kappa values <0.6, between 0.6 and 0.8, and >0.8 were  
163 considered to represent poor, moderate, and good agreement, respectively.

164

## 165 **Results**

166 During the study period, 109 pregnant women with suspicion of foetal MMC were  
167 referred to our centre (**figure 3**). The diagnosis was revised in 26 cases including limited  
168 dorsal myeloschisis (LDM)<sup>14</sup> (n=9) or borderline types of LDM-MMC (n=14), the latter  
169 being characterized by the association between a saccular dysraphism with a thick  
170 membrane coverage, a spinal cord stretched to the sac wall by a fibrous stalk, the  
171 absence of nerve roots within the sac and either a Chiari type 2 malformation or a  
172 reduced cisterna magna. Moreover, other types of dysraphisms were observed,  
173 including lipomyelomeningocele (n=1), complex dysraphism (n=1) and meningocele  
174 (n=1). The diagnosis of MMC was confirmed in 83 cases. Thirteen cases were excluded:  
175 polymalformative syndromes (n=6), MMC with associated diastematomyelia (n=3), TOP

176 before 20 weeks of gestation (n=2) and cases for which satisfying study of the corpus  
177 callosum was not available due to foetal position (n=2). **In these latter two cases, MRI**  
178 **was not performed since the parents opted for TOP and declined the PM**  
179 **examination.** The remaining 70 cases of MMC were included. **Fetal karyotype**  
180 **analysis was performed in 39/70 cases and revealed no chromosomal anomalies.**

181

## 182 **Prenatal imaging findings**

183 The median GA at second line US examination was 23 weeks<sup>+3d</sup> (range: 20  
184 weeks<sup>+3d</sup> - 25 weeks<sup>+6d</sup>). **The uppermost vertebral defect was below L3 in 45/70**  
185 **cases (64%). Foetal talipes was associated with MMC in 20/70 cases (29%). A**  
186 **Chiari type 2 malformation was observed in all cases. A microcephaly was**  
187 **observed in 32/70 cases (46%), a ventriculomegaly was observed in 39/70 cases**  
188 **(56%). Overall, other cerebral anomalies were diagnosed in 47/70 (67%) of the**  
189 **cases in the prenatal period. We observed 42/70 cases with abnormal CC (60%),**  
190 **8/70 cases with PNH (11%), 2/70 cases with abnormal gyration (3%). Additional**  
191 **fetal MRI was performed in 12/70 cases (17%) only in cases where foetal surgery**  
192 **was considered. MRI confirmed US findings in all cases, and provided additional**  
193 **findings in 2 cases (PNH).**

194

## 195 ***MMC associated with ventriculomegaly***

196 **In cases associated with ventriculomegaly, no additional cerebral**

197 anomalies were observed in 10/39 cases (26%) (figure 3). In all these cases,  
198 patients opted for TOP and when performed, no additional findings were identified  
199 on PM examination. In the remaining 29 cases, the parents opted for prenatal  
200 repair in 6 cases, for conventional postnatal repair in 6, and for TOP in 17 cases.

201 The CC was considered as abnormal in 26/39 cases (67%). The CC was  
202 stretched in 5 cases, associated with ventriculomegaly  $\geq 13$  mm in all these cases.  
203 The CC was considered short and complete in 10 cases , and short but incomplete  
204 in 10 other cases. When the CC was short, it was thickened in 11/20 cases. There  
205 was a complete CC agenesis in one case.

206 PNH were diagnosed by prenatal imaging in 6/39 cases (15%). In four cases,  
207 they were detected at the second line of ultrasound examination. In addition, in  
208 two other cases, PNH were detected at systematic MRI examination performed as  
209 part of the management of prenatal surgery cases.

210 Abnormal gyration pattern was observed in 2/39 cases (5%) at the second  
211 line ultrasound examination only. In one case, the CC was normal and in the other  
212 case, the CC was short but complete. In these 2 cases, MRI was not performed  
213 and PM was declined.

#### 214 *MMC without ventriculomegaly*

215 In cases not associated with ventriculomegaly, no additional cerebral  
216 anomalies were observed in 13/31 cases (42%) (figure 3). Among these cases,  
217 parents opted for prenatal repair in 3 cases, for conventional postnatal repair in 4

218 **cases, and for TOP in 6 cases.**

219 **The CC was considered as abnormal in 16/31 cases (52%). The CC was**  
220 **considered short and complete in 14 cases, and short but incomplete in 2 other**  
221 **cases. When the CC was short, it was thickened in 2/16 cases.**

222 **PNH were diagnosed by prenatal imaging in 2/31 cases (6%). In one case,**  
223 **PNH was detected at the second line of ultrasound examination and confirmed by**  
224 **MRI. In the other case, PNH was detected at the systematic MRI examination. No**  
225 **case of abnormal gyration pattern was observed.**

226

#### 227 **Perinatal outcome**

228 **Overall, there were 25/70 liveborn neonates including 13 (52%) cases that**  
229 **underwent a prenatal repair performed at a median age of 24<sup>+5d</sup> weeks (range: 21**  
230 **weeks<sup>+3d</sup>-25 weeks<sup>+6d</sup>) (figure 4). One neonatal death occurred in one case at day 9**  
231 **(postnatal repair group). Ventriculo-peritoneal shunt was indicated in 3 and 6**  
232 **children in the prenatal repair and postnatal repair groups, respectively. The 24**  
233 **live children are currently 6 to 40 months old with normal neurobehavioral**  
234 **development, including the 10 and the 5 cases with either PNH or CC anomalies in**  
235 **the prenatal surgery group and postnatal repair group, respectively.**

236 **A TOP was elected by the parents in 45 cases and a PM examination was**  
237 **performed in 39 cases. Detection of associated CNS anomalies (CC anomalies,**  
238 **PNH or abnormal gyration) was not significantly associated with a decision of**

239 **TOP (OR=1.2, p=0.06). Risk ratios of foetal cerebral anomalies associated with**  
240 **MMC did not reach significance for microcephaly, ventriculomegaly, talipes and**  
241 **for the level of the defect (Figure S1).**

242

### 243 **Correlation between prenatal imaging and postnatal or post-mortem findings**

244 A complete review of the prenatal and postnatal imaging was possible in 18/25  
245 live born neonates. Among the cases with a complete CC assessed prenatally, there  
246 were 2 cases with complete but stretched CC associated with a postnatal  
247 ventriculomegaly. There was an overall good correlation between pre and postnatal  
248 findings with a Kappa value of 0.79 [0.57-1]<sub>CI95%</sub> and a proportion of agreement of 82%.

249

250

## 251 **Discussion**

### 252 Main findings

253 **Foetal cerebral anomalies in case of MMC have been widely described and**  
254 **comprise Chiari II malformation, ventriculomegaly and microcephaly. Our study**  
255 **suggests that other cerebral anomalies may be present in up to 67% of the cases.**

256 CC anomalies were the most frequent (60%). Other anomalies included heterotopia or  
257 suspicion of gyration disorders.

258

### 259 Strengths and limitations

260 The strength of our study is represented by the fact that all cases were evaluated  
261 by an experienced sonographer in foetal brain imaging with an independent review  
262 performed by two observers blinded to the perinatal outcome using a standardized grid.  
263 In addition, we were able to demonstrate a good correlation between prenatal and  
264 postnatal imaging. However, considering the retrospective design of our study,  
265 correlation between prenatal imaging findings and PM examination was possible in only  
266 40% of the cases in which the parents opted for TOP. Moreover, we observed some  
267 discrepancies between prenatal imaging and PM examination in up to 50% of the cases.  
268 This was in part the consequence of an absence of standardised grid and curves for  
269 examination of the CC at PM examination. In line with this, we observed that CC  
270 considered with abnormal length at prenatal imaging were classified as normal at PM  
271 examination.

272

### 273 Interpretations

274 Some structural anomalies are virtually unique to patients with MMC and are  
275 mainly represented **by a complex pattern of cerebral dysplasia known as Chiari II**  
276 **malformation, ventriculomegaly and microcephaly**<sup>3,4,15</sup>. Other cerebral anomalies,  
277 not **specific** to MMC, have been reported in cohorts of children and adults<sup>4</sup>. Among  
278 these lesions, CC anomalies are present in up to 70 to 90% of **postnatal cases**<sup>16-19</sup>.  
279 The most frequent CC anomalies comprise mainly CC hypoplasia, usually partial  
280 hypoplasia of the genu and body, but also CC partial agenesis (mostly rostrum  
281 agenesis)<sup>6,16</sup>. Complete CC agenesis remains extremely rare in this population<sup>6,16</sup>. The  
282 underlying pathological mechanism of these CC anomalies remains debatable. **In case**  
283 **of postnatal hydrocephalus, the CC often appears as stretched and thin and is**

284 **considered as a usual finding<sup>3</sup>. Similarly, significant ventriculomegaly could be**  
285 **the underlying mechanism of the stretched CC feature we observed in 5 fetuses**  
286 **in our series. In the prenatal period, the high prevalence of early ventriculomegaly**  
287 **in case of MMC also raises the question of its impact on CC development, which**  
288 **is critical between 19 and 21 weeks, with significant growth of the splenium until**  
289 **24 weeks<sup>12,20</sup>. Interestingly, our rate of CC anomalies of 60% appears to be lower than**  
290 **reported in children or adults patients<sup>6,16-18</sup>. We also described a novel feature of**  
291 **short CC < 3<sup>rd</sup> centile, a majority of them < 1<sup>st</sup> centile (60% of cases), whether**  
292 **complete or incomplete and, in some cases, associated to a thickened feature.**  
293 **These CC anomalies were observed in cases, either with normal ventricular**  
294 **measurement or with moderate ventriculomegaly at midgestation. This casts**  
295 **doubt on a possible causal relationship between ventriculomegaly and CC**  
296 **anomalies and is a clue pointing to the existence of a spectrum of abnormalities**  
297 **of brain development in fetuses with MMC. Also, we would like to highlight the**  
298 **fact that in our experience (unpublished data), it is not possible to thoroughly**  
299 **discriminate a short but complete CC and a CC with very partial agenesis using**  
300 **current foetal imaging techniques. Thus, some CC considered short but complete**  
301 **in this study might be erroneously classified. Overall, the existence of these**  
302 **additional callosal anomalies raises the question of their impact on the postnatal**  
303 **development of these children and requires further evaluation. Indeed, even in**  
304 **normal fetuses, the prognosis of short or thick CC remains a matter of debate**  
305 **considering the very few data available<sup>21-23</sup>.**

306 **Besides these already known CC anomalies associated with MMC, we also found**  
307 **PNH and cortical anomalies in 11% and 3% of the cases respectively. Interestingly, in**

308 one of the two prenatal cases in **which** abnormal Sylvian appearance was suspected,  
309 gyration was considered as normal at postnatal imaging. Excessive thinness of the  
310 pericerebral space in foetuses with MMC makes it difficult to properly analyse the  
311 sylvian fissure and it probably accounts for one case being **inappropriately** classified as  
312 gyration abnormalities **at** the beginning of the study. The impact of these cortical  
313 associated malformations on the postnatal neurobehavioral development also requires  
314 further assessment.

315         The timing of the prenatal diagnosis of these associated cerebral anomalies  
316 requires specific attention, especially within the context of fetal surgery for MMC. The  
317 majority of the centres offering prenatal repair for MMC, whatever the technique used  
318 (open v. fetoscopic surgery), do comply with the MoM study criteria. Thus, only cases of  
319 isolated MMC are eligible to a prenatal repair<sup>9</sup>. The common associated findings, such  
320 as **talipes**, do not preclude prenatal surgery<sup>9</sup>. **In our centre, 10/13 cases with foetal**  
321 **surgery were found to be associated with cerebral anomalies suspected in the**  
322 **prenatal period and represented by short CC in 7 cases and/or PNH in 6 cases. In**  
323 **the first five cases, these anomalies were suspected between 28 to 32 weeks after**  
324 **foetal surgery had been performed. All these children, although still young, 24**  
325 **months to four years old at the moment, display normal development. In the other**  
326 **five cases, either short appearance of the CC or suspicion of PNH were suspected**  
327 **before foetal surgery. The parents were informed of these findings and maintained**  
328 **their request for a prenatal repair.** Considering the high rate of CC anomalies in the  
329 postnatal series and the favourable outcome of isolated PNH in non-MMC foetuses<sup>24,25</sup>,  
330 we did not consider these findings as a contraindication for a prenatal repair. However,  
331 these children will require specific neurobehavioral development follow-up in the future.



332  
333  
334  
335  
336  
337  
338  
339  
340  
341  
342  
343  
344  
345  
346  
347  
348  
349  
350  
351  
352  
353  
354  
355

**Conclusion**

We conclude that foetal brain anomalies other than **Chiari II malformation, ventriculomegaly and microcephaly** are frequently observed during the prenatal period in foetuses with MMC and are predominantly represented by CC anomalies. **Whether these associated cerebral anomalies should have an impact on selecting cases eligible to a foetal surgery needs further evaluation.**

Disclosure of interest:

Non declared. Completed disclosure of interest forms are available to view online as supporting information.

Contribution to authorship:

JMJ, CG and PM contributed to the conception and design of the study and to drafting the work. PM and JG reviewed all prenatal and postnatal imaging. LG, EM, SF, FD, HDL and EB provided the statistical analysis and interpretation of data, and revised it critically for important intellectual content. All authors read and approved the final manuscript.

Details of ethical approval:

Clinical Trial registration NCT01983345; Institutional Review Board approval 13048 **Comité de Protection des Personnes Ile de France XI**, 04<sup>th</sup> July 2013.

356 Funding statement:

357 This study was funded by a grant from the Programme Hospitalier de Recherche  
358 Clinique – PHRC 2013 (French Ministry of Health) and was promoted by La Délégation  
359 à la Recherche Clinique et l'Innovation de l'AP-HP (Assistance Publique Hôpitaux de  
360 Paris).

361

362

### 363 **References**

364 1- Khoshnood B, Loane M, de Walle H, Arriola L, Addor MC, Barisic I et al. Long term  
365 trends in prevalence of neural tube defects in Europe: population based study.  
366 BMJ. 2015; 351: h5949.

367 2- Adzick NS. Fetal surgery for spina bifida: past, present, future. Semin Pediatr Surg  
368 2013; 22: 10–17.

369 3- Juranek J. Anomalous development of brain structure and function in spina bifida  
370 myelomeningocele. Dev Disabil Res Rev 2010;16:23-30.

371 4- Januschek E, Röhrig A, Kunze S, Fremerey C, Wiebe B, Messing-Jünger M.  
372 Myelomeningocele – a single institute analysis of the years 2007 to 2015. Childs  
373 Nerv Syst 2016; 32: 1281–1287.

374 5- Beuriat PA, Szathmari A, Rousselle C, Sabatier I, Di Rocco F, Mottolese C. Complete  
375 reversibility of the Chiari type II malformation after postnatal repair of  
376 myelomeningocele. World Neurosurg 2017; 108: 62–68.

377 6- Hannay HJ, Dennis M, Kramer L, Blaser S, Fletcher JM. Partial agenesis of the  
378 corpus callosum in spina bifida meningomyelocele and potential compensatory  
379 mechanisms. J. Clin. Exp. Neuropsychol 2009;31:180-194.

380 7- Barkovich, J. Pediatric neuroimaging. Philadelphia, PA: Lippincott, Williams &  
381 Wilkens; 2005.

382 8- Friszer S, Dhombres F, Di Rocco F, Rigouzzo A, Garel C, Guilbaud L et al.  
383 Preliminary results from the French study on prenatal repair for fetal myelomeningoceles  
384 (the PRIUM study). J Gynecol Obstet Biol Reprod. 2016 Sep;45(7):738-44.

385 9- Adzick NS, Thom EA, Spong CY, Brock JW 3rd, Burrows PK, Johnson MP, et al.;  
386 MOMS Investigators. A randomized trial of prenatal versus postnatal repair of  
387 myelomeningocele. N Engl J Med 2011;364: 993-1004.

388 10- Salomon LJ, Duyme M, Crequat J, Brodaty G, Talmant C, Fries N et al.  
389 French fetal biometry: reference equations and comparison with other charts.  
390 Ultrasound Obstet Gynecol. 2006 Aug;28(2):193-8.

391 11- Cignini P, Padula F, Giorlandino M, Brutti P, Alfo M, Giannarelli D et al. Reference  
392 charts for fetal corpus callosum length. J Ultrasound Med 2014;33:1065-1078.

393 12- Achiron R and Achiron A. Development of the human fetal corpus callosum: a high-  
394 resolution, cross-sectional sonographic study. Ultrasound Obstet Gynecol 2001;18:343-  
395 347.

396 13- Garel C, Cont I, Alberti C, Josserand E, Moutard ML, Ducou le Pointe H. Biometry of  
397 the corpus callosum in children: MR imaging reference data. AJNR Am J Neuroradiol.  
398 2011 Sep;32(8):1436-43.

399 14- Friszer S, Dhombres F, Morel B, Zerah M, Jouannic JM, Garel C. Limited Dorsal  
400 Myeloschisis: A Diagnostic Pitfall in the Prenatal Ultrasound of Fetal Dysraphism. Fetal  
401 Diagn Ther. 2017;41(2):136-144.

- 402 15- McLone DG, Knepper PA. The cause of Chiari II malformation: a unified theory.  
403 *Pediatr Neurosci.* 1989; 15:1–12.
- 404 16- Miller E, Widjaja E, Blaser S, Dennis M, Raybaud C. The old and the new:  
405 supratentorial MR findings in Chiari II malformation. *Childs Nerv. Syst.* 2008;245:563–  
406 575, May 2008.
- 407 17- Elgamal EA, Elwatidy SM, Alhabib AF, Jamjoom ZB, Murshid WR, Hassan HH et al.  
408 Agenesis of the corpus callosum associated with spinal open neural tube defect. *Saudi*  
409 *Med J.* 2014 Dec;35 Suppl 1:S57-63.
- 410 18- Herweh C, Akbar M, Wengenroth M, Blatow M, Mair-Walther J, Rehbein N et al.  
411 DTI of commissural fibers in patients with Chiari II-malformation. *Neuroimage.* 2009 Jan  
412 15;44(2):306-11.
- 413 19- Crawley JT, Hasan K, Hannay HJ, Dennis M, Jockell C, Fletcher JM. Structure,  
414 integrity, and function of the hypoplastic corpus callosum in spina bifida  
415 myelomeningocele. *Brain Connect.* 2014 Oct;4(8):608-18.
- 416 20- Malinger G and Zakut . The corpus callosum: normal fetal development as shown by  
417 transvaginal sonography. *AJR Am. J. Roentgenol.* 1993;161:1041–1043.
- 418 **21- Meidan R, Bar-Yosef O, Ashkenazi I, Yahal O, Berkenstadt M, Hoffman C et al.**  
419 **Neurodevelopmental outcome following prenatal diagnosis of a short corpus**  
420 **callosum. *Prenat Diagn.* 2019 May;39(6):477-483.**
- 421 **22- Lerman-Sagie T, Ben-Sira L, Achiron R, Schreiber L, Hermann G, Lev D et al.**  
422 **Thick fetal corpus callosum: an ominous sign? *Ultrasound Obstet Gynecol.* 2009**  
423 **Jul;34(1):55-61.**

424 **23- Shinar S, Har-Toov J, Lerman-Sagie T, Malinger G. Thick corpus callosum in**  
425 **the second trimester can be transient and is of uncertain significance. Ultrasound**  
426 **Obstet Gynecol. 2016;48:452-457.**

427 24- Deloison B, Sonigo P, Millischer-Bellaiche AE, Quibel T, Cavallin M, Benoist G et al.  
428 Prenatally diagnosed periventricular nodular heterotopia: Further delineation of the  
429 imaging phenotype and outcome. Eur J Med Genet. 2018 Dec;61(12):773-782.

430 **25- Blondiaux E, Sileo C, Nahama-Allouche C, Moutard ML, Gelot A, Jouannic JM**  
431 **et al. Perinodular heterotopia on prenatal ultrasound and magnetic resonance**  
432 **imaging. Ultrasound Obstet Gynecol. 2013 Aug;42(2):149-55.**

433

434

435

436 **Legend to the figures:**

437 **Figure 1: Ultrasound midsagittal view of the brain in a foetus at 25 weeks with**  
438 **myelomeningocele (uppermost vertebral defect level L3). Short (length < 3<sup>rd</sup>**  
439 **centile) but complete corpus callosum (arrows).**

440  
441 **Figure 2: Foetus at 24 weeks with myelomeningocele (uppermost vertebral defect**  
442 **level L3). Short (length < 1<sup>st</sup> centile) thickened and incomplete corpus callosum**  
443 **(arrows) with suspicion of rostrum and splenium agenesis. Midsagittal view of**  
444 **the brain: A ultrasound image, and B : T2 weighted MRI image.**

445  
446 **Figure 3:** Flow chart of the dysraphism cases. MMC: myelomeningocele; LDM: limited  
447 dorsal myeloschisis; TOP: termination of pregnancy; CC: corpus callosum; PNH:  
448 perinodular heterotopia.

449  
450 **Figure 4: Flow chart of the perinatal outcome of the 70 myelomeningocele cases.**  
451 MMC: myelomeningocele; CC: corpus callosum; PNH: perinodular heterotopia.

452  
453 **Figure S1: Risk ratio of foetal cerebral anomalies other than Chari type 2**  
454 **malformation in the 70 myelomeningocele cases. HC: head circumference.**