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Epidemiology of congenital heart defects in France from 2013 to 2022 using the PMSI-MCO (French Medical Information System Program in Medicine, Surgery, and Obstetrics) database

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Abstract

Background

Congenital heart defects are common and occur in approximately 0.9% of births. In France, the registries cover approximately 20% of the population but not the entirety of France; therefore, we aimed to update the incidence data for congenital heart defects in France from 2013 to 2022 using the medico-administrative database PMSI-MCO (French Medical Information System Program in Medicine, Surgery, and Obstetrics). We aimed to compare the frequency of risk factors in a population with congenital heart defects and a reference population.

Methods

From 2013 to 2022, we included children aged < 3 years diagnosed with congenital heart defects according to the International Classification of Diseases, 10th Revision, in the PMSI-MCO database. We compared them with a population without congenital defects on several medical data items (e.g., parity, gemellarity, and mortality rate). Bivariate and multivariate analyses compared children with congenital heart defects and children without congenital malformation.

Results

We identified 83,879 children with congenital heart defects in France from 2013 to 2022 in the PMSI-MCO database and 7,739,840 children without such defects, including 7,218,952 without any congenital defects. We observed more deaths (7.49% vs. 0.68%, d = 0.59) and more twinning (8.67% vs. 1.23%, d = 0.35) among children with congenital heart defects. Multivariate analysis revealed an increased risk of congenital heart defects in male

database (French Medical Information System Program) is restricted to authorized professionals (with individual access). Likewise, data collected are confidential, only worked data can be disseminated like in our work. To access raw data, one should contact some french professional authorized to access the PMSI (or the institution must request access to the database: demande_base@atih.sante.fr).

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individuals (OR [odds ratio] 1.056, 95% CI [confidence interval] [1.039–1.076]) and cases of medically assisted reproduction (OR 1.115, 95% CI [1.045–1.189]) and a reduced risk in the case of multiparity (OR 0.921, 95% CI [0.905–0.938]).

Conclusions

According to the PMSI-MCO database, the incidence of congenital heart defects in France from 2013 to 2022 is 1% of births. Congenital heart defects are more frequent in cases of prematurity, twinning, primiparity, male sex, and maternal age > 40 years.

Introduction

Congenital defects are common, with an estimated incidence of 25 per 1,000 births, including 30% heart defects according to the European Surveillance of Congenital Anomalies (EUROCAT) database [1–3]. The incidence of congenital heart defects (CHDs) is increasing, partly because they are better diagnosed, especially since the advent of ultrasonography, and better managed, reducing perinatal deaths and pregnancy termination [4–8]. The overall incidence varies slightly from one region of the world to another but varies according to the CHD considered [4, 9–12]. The life expectancy of patients with CHD is increasing, and its prevalence in adulthood is 4 per 1,000 [13, 14]. This trend calls for regular epidemiological monitoring to adapt healthcare policies.

In France, published epidemiological data are from registers [15–17]. French registries are included in the EUROCAT database [3]. However, these registries are imperfect. An analysis of the systems for monitoring congenital defects was published by the French National Authority for Health (Haute Autorité de Santé [HAS]), which reviewed the strengths and weaknesses of registers [18]. Registries have a good quality of diagnosis but lack completeness in terms of territorial coverage (approximately 20% of France) and do not pool their data. They do not have the same inclusion criteria; for example, one may use the International Statistical Classification of Diseases and Related Health Problems– 10th Revision (ICD-10), whereas another uses a limited list of CHDs [17, 19–21]. In addition, no data are available for some years. Proposals have been made to improve these but this will require time, especially in terms of structuring, harmonizing, and pooling.

There are other databases in France, such as the French Public and Private Hospital Databases with the French Medical Information System Program (*Programme de Médicalisation des Systèmes d'Information* [PMSI]). It is a large national data-base that has shown reliability in numerous epidemiological studies [22–26]. It is used when patients are admitted or hospitalized by coding according to the World Health Organization (WHO) rules and, since 1996, the ICD-10 [20, 21, 27, 28]. The PMSI database collects patients' main and associated diagnoses according to the ICD-10 and sociodemographic data, such as age, sex, and weight. The ICD-10 includes CHD diagnoses and their known risk factors, such as maternal diabetes and trisomy 21 [29, 30]. All information is anonymized using a unique identifier; this avoids duplicates and identifies multiple stays of the same patient, without the possibility of lifting anonymity. For newborns, the PMSI coding is systematic if they are born in a hospital or hospitalized after home delivery. Since 2012, mother-child data have been linked to the PMSI [31].

Our aim was to update French epidemiological data on CHD from 2013 to 2022 using the PMSI database. We also aimed to compare the frequency of the risk factors for CHD in children with CHD and a reference population.

Materials and methods

Our study followed the French reference methodology MR-005, which regulates access to the PMSI database in accordance with current French Data Protection Authority regulations (Commission Nationale de l'Informatique et des Libertés [CNIL]) [32]. The access to the PMSI database was made available by the French National Agency for the Management of hospitalization data [28]. This was a retrospective, longitudinal, non-interventional study based on an anonymous database. The study did not require patient consent and was registered under CNIL's registration number 2205141.

Study population and data sources

The inclusion criteria were child < 3 years of age, included in the database between 2013 and 2022 in France, and a diagnosis of CHD according to the ICD-10 (codes Q20 to Q26) [21]. Fetal deaths in utero and pregnancy terminations were also included in the study. The exclusion criteria were as follows: patients residing outside France or with an unspecified place of residence, incorrect French diagnosis-related groups, and incorrect patient identifiers. The reference population consisted of children aged < 3 years between 2013 and 2022 with no diagnosis of congenital defects (absence of any ICD-10 Q code).

PMSI-MCO (médecine-chirurgie-obstétrique [Medicine, Surgery, and Obstetrics]) data were collected between 2013 and 2022. Data from the French Overseas Departments or Regions and Overseas Collectivities (DROM-COM [Départements ou Régions français d'Outre-Mer et les Collectivités d'Outre-Mer]) were analyzed separately. Linking was performed with PMSI-HAD (*hospitalisation à domicile* [home hospitalization]) and mother-child data to increase data reliability.

The CHD diagnoses for ICD-10 codes Q20.0 to Q26.9 were collected, both separately as a single CHD diagnosis and in association with multiple CHD diagnoses. We collected the frequencies of different CHDs.

Medical, social, and demographic data were collected from the patients with CHDs and the reference population. The variables of interest were age at the time of diagnosis, sex, gestational age, birth weight, term of birth, mother's age at birth, parity, route of birth and extraction, whether the child underwent medically assisted reproduction (MAR), death, and age at death.

The data from the ICD-10 codes investigated were: palliative care decision (Z51.5), chromosomal abnormalities (Q90 to Q99), fetus and newborn affected by maternal factors and complications of pregnancy, labor, and delivery (P00 to P04), disorders related to length of gestation and fetal growth (P05 to P08), maternal gestational diabetes (P70.0), maternal diabetes (P70.1), and neonatal withdrawal symptoms from maternal use of drugs of addiction (P96.1). We retained the diagnosis of transposition of the great arteries (TGA) or common arterial trunk in cases of an associated diagnosis of tetralogy of Fallot (ToF) to eliminate some border pathologies.

Statistical analysis

Categorical variables were presented as absolute numbers and percentages. Continuous variables were presented in classes: ≤ 1 month and 1–36 months for the age of diagnosis; ≤ 30 days, 31–365 days, and > 365 days for the days of life; < 24 weeks, 24–36 weeks, and > 36 weeks for the term of birth; < 500 g, 500–1999 g, 2000–3999 g, and ≥ 4000 g for the birth weight; and ≤ 18 years, 18–30 years, 31–39 years, and ≥ 40 years for the maternal age. The chi-square test was used to compare categorical variables. Because the magnitude of statistical significance is heavily influenced by sample size, comparisons between the two groups were

also expressed in terms of the standardized difference score (d, as an absolute number) to provide a more robust and reliable estimation of group divergence [33]. Cohen suggested that d = 0.2, 0.5, and 0.8 represents a small, medium, and large effect size, respectively [34]. Risk factors for CHDs were determined based on their clinical relevance and existing data in the literature using logistic regression. Multiple births were included; therefore, the mothers were included more than once in these situations. A random effects term was introduced to account for these situations. The analyses were performed using the secure platform of the Agence Technique de l'Information Hospitalière. Data extraction and statistical analyses were performed using SAS Guide Enterprise version 8.2. Standardized difference scores were calculated using a specific SAS macro [35].

Results

Population

From 2013 to 2022, 88,759 children met the inclusion criteria (83,879 in mainland France and 4,880 in French overseas departments and territories) after excluding erroneous stays and dubious anonymous numbers.

The population without CHD included 8,078,838 children (7,739,840 from metropolitan France and 338,998 from DROM-COM). The reference comparison population without congenital malformations according to ICD-10 codes comprised 7,535,862 children (7,218,952 from mainland France and 316,910 from DROM-COM).

Epidemiology of CHDs

The incidence of CHDs was 10.7 per 1,000 births in mainland France and 14.2 per 1,000 births in French overseas departments and territories.

The incidence of CHDs for each ICD-10 code in mainland France is shown in Table 1 (incidence of CHDs in DROM-COM in the S1 Table). In cases of association, each code was counted individually; therefore, certain categories of CHDs exceeded 100%. For example, cardiac septal defects accounted for 111.38% of multiple diagnoses, as the codes for ventricular septal defects (VSDs) and atrial septal defects (ASDs) were counted separately, although some children could have had both.

Table 2 shows the frequencies of certain associations in mainland France. The most frequent associations were between VSD and ASD (6.05% of CHD diagnoses), Coarctation of aorta (CoA) and VSD (1.73%), and TGA and VSD (1.46%).

Comparison of CHD

Table 3 compares children in metropolitan France with CHDs and those without congenital defects (data from the DROM-COM in the S2 Table). A strong relationship of CHD with prematurity (d = 0.86), maternal arterial hypertension (d = 0.26), and twinning (d = 0.35) was observed. Death occurred more frequently among patients with CHD (d = 0.59). Sex and maternal age did not differ between children with CHD and children without congenital malformations in the univariate analysis (d = 0.01 and d = 0.15, respectively).

N: number; **P00.0:** Fetus and newborn affected by maternal hypertensive disorders; **P01.5:** Fetus and newborn affected by multiple pregnancy; **P05.0:** Light for gestational age; **P70.0:** Syndrome of infant of mother with gestational diabetes; **P70.1:** Syndrome of infant of a mother with diabetes; **P96.1:** Neonatal withdrawal symptoms from maternal use of drugs of addiction; **d**: standardized differences score.

Table 1. Incidence of congenital heart defects in metropolitan France from 2013 to 2022 in the PMSI-MCO (French Medical Information System Program in Medicine, Surgery and Obstetrics) database according to the ICD-10 (International Statistical Classification of Diseases– 10th Revision).

ICD-10 code		Unique diagnosis		Multiple diagnoses		Total	
	Number of patients	**61,171**	**72.93%**	**22,708**	**27.07%**	**83,879**	**100.00%**
Q20	**Congenital malformations of cardiac chambers and connections**	**1,894**	**3.10%**	**6,261**	**27.57%**	**8,155**	**9.72%**
Q200	Common arterial trunk	127	0.21%	313	1.38%	440	0.52%
Q201	Double outlet right ventricle	62	0.10%	960	4.23%	1,022	1.22%
Q202	Double outlet left ventricle	12	0.02%	102	0.45%	114	0.14%
Q203	Discordant ventriculoarterial connection	666	1.09%	2,143	9.44%	2,809	3.35%
Q204	Double inlet ventricle	92	0.15%	977	4.30%	1,069	1.27%
Q205	Discordant atrioventricular connection	36	0.06%	449	1.98%	485	0.58%
Q206	Isomerism of atrial appendages	18	0.03%	126	0.55%	144	0.17%
Q208	Other congenital malformations of cardiac chambers and connections	652	1.07%	759	3.34%	1,411	1.68%
Q209	Congenital malformation of cardiac chambers and connections, unspecified	229	0.37%	432	1.90%	661	0.79%
Q21	**Congenital malformations of cardiac septa**	**28,724**	**46.96%**	**25,293**	**111.38%**	**54,017**	**64.40%**
Q210	Ventricular septal defect	13,753	22.48%	10,811	47.61%	24,564	29.29%
Q211	Atrial septal defect	12,187	19.92%	10,138	44.65%	22,325	26.62%
Q212	Atrioventricular septal defect	887	1.45%	1,961	8.64%	2,848	3.40%
Q213	Tetralogy of Fallot	1,398	2.29%	1,838	8.09%	3,236	3.86%
Q214	Aortopulmonary septal defect	58	0.09%	183	0.81%	241	0.29%
Q218	Other congenital malformations of cardiac septa	377	0.62%	291	1.28%	668	0.80%
Q219	Congenital malformation of cardiac septum, unspecified	64	0.10%	71	0.31%	135	0.16%
Q22	**Congenital malformations of pulmonary and tricuspid valves**	**1,758**	**2.87%**	**5,520**	**24.31%**	**7,278**	**8.68%**
Q220	Pulmonary valve atresia	114	0.19%	959	4.22%	1,073	1.28%
Q221	Congenital pulmonary valve stenosis	1,088	1.78%	1,976	8.70%	3,064	3.65%
Q222	Congenital pulmonary valve insufficiency	30	0.05%	262	1.15%	292	0.35%
Q223	Other congenital malformations of pulmonary valve	108	0.18%	519	2.29%	627	0.75%
Q224	Congenital tricuspid stenosis	42	0.07%	436	1.92%	478	0.57%
Q225	Ebstein anomaly	144	0.24%	185	0.81%	329	0.39%
Q226	Hypoplastic right heart syndrome	36	0.06%	495	2.18%	531	0.63%
Q228	Other congenital malformations of tricuspid valve	167	0.27%	567	2.50%	734	0.88%
Q229	Congenital malformation of tricuspid valve, unspecified	29	0.05%	121	0.53%	150	0.18%
Q23	**Congenital malformations of aortic and mitral valves**	**1,352**	**2.21%**	**5,186**	**22.84%**	**6,538**	**7.79%**
Q230	Congenital stenosis of aortic valve	179	0.29%	788	3.47%	967	1.15%
Q231	Congenital insufficiency of aortic valve	362	0.59%	1,216	5.35%	1,578	1.88%
Q232	Congenital mitral stenosis	21	0.03%	624	2.75%	645	0.77%
Q233	Congenital mitral insufficiency	209	0.34%	833	3.67%	1,042	1.24%
Q234	Hypoplastic left heart syndrome	409	0.67%	1,059	4.66%	1,468	1.75%
Q238	Other congenital malformations of aortic and mitral valves	131	0.21%	523	2.30%	654	0.78%
Q239	Congenital malformation of aortic and mitral valves, unspecified	41	0.07%	143	0.63%	184	0.22%
Q24	**Other congenital malformations of heart**	**4,633**	**7.57%**	**7,334**	**32.30%**	**11,967**	**14.27%**
Q240	Dextrocardia	134	0.22%	305	1.34%	439	0.52%
Q241	Levocardia	178	0.29%	480	2.11%	658	0.78%
Q242	Cor triatriatum	27	0.04%	69	0.30%	96	0.11%
Q243	Pulmonary infundibular stenosis	21	0.03%	501	2.21%	522	0.62%
Q244	Congenital subaortic stenosis	49	0.08%	429	1.89%	478	0.57%
Q245	Malformation of coronary vessels	308	0.50%	549	2.42%	857	1.02%
Q246	Congenital heart block	128	0.21%	56	0.25%	184	0.22%
Q248	Other specified congenital malformations of heart	2,351	3.84%	2,422	10.67%	4,773	5.69%

(*Continued*)

Table 1. (Continued)

ICD-10 code		Unique diagnosis		Multiple diagnoses		Total	
Q249	Congenital malformation of heart, unspecified	1,437	2.35%	2,523	11.11%	3,960	4.72%
Q25	**Congenital malformations of great arteries**	**22,028**	**36.01%**	**16,488**	**72.61%**	**38,516**	**45.92%**
Q250	Patent ductus arteriosus	18,398	30.08%	6,249	27.52%	24,647	29.38%
Q251	Coarctation of aorta	1,363	2.23%	2,913	12.83%	4,276	5.10%
Q252	Atresia of aorta	24	0.04%	399	1.76%	423	0.50%
Q253	Stenosis of aorta	104	0.17%	482	2.12%	586	0.70%
Q254	Other congenital malformations of aorta	844	1.38%	1,872	8.24%	2,716	3.24%
Q255	Atresia of pulmonary artery	59	0.10%	802	3.53%	861	1.03%
Q256	Stenosis of pulmonary artery	678	1.11%	1,938	8.53%	2,616	3.12%
Q257	Other congenital malformations of pulmonary artery	198	0.32%	726	3.20%	924	1.10%
Q258	Other congenital malformations of great arteries	262	0.43%	689	3.03%	951	1.13%
Q259	Congenital malformation of great arteries, unspecified	98	0.16%	418	1.84%	516	0.62%
Q26	**Congenital malformations of great veins**	**782**	**1.28%**	**2,373**	**10.45%**	**3,155**	**3.76%**
Q260	Congenital stenosis of vena cava	4	0.01%	19	0.08%	23	0.03%
Q261	Persistent left superior vena cava	172	0.28%	464	2.04%	636	0.76%
Q262	Total anomalous pulmonary venous connection	114	0.19%	437	1.92%	551	0.66%
Q263	Partial anomalous pulmonary venous connection	40	0.07%	370	1.63%	410	0.49%
Q264	Anomalous pulmonary venous connection, unspecified	42	0.07%	439	1.93%	481	0.57%
Q265	Anomalous portal venous connection	13	0.02%	16	0.07%	29	0.03%
Q266	Portal vein-hepatic artery fistula	94	0.15%	63	0.28%	157	0.19%
Q268	Other congenital malformations of great veins	267	0.44%	501	2.21%	768	0.92%
Q269	Congenital malformation of great vein unspecified	36	0.06%	64	0.28%	100	0.12%

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In the multivariate analysis, maternal age > 40 years was a risk factor for CHD (OR 1.310, $p < 0.001$) (Fig 1 for metropolitan France; data in S1 Fig for DROM-COM). Similarly, male sex and pregnancy resulting from MAR were associated with an increased risk of CHD (OR, 1.057 and 1.115, respectively; $p < 0.001$), whereas multiparity had a protective effect against CHD (OR 0.921, $p < 0.001$).

Discussion

Interpretation of results

To our knowledge, this is the first study to calculate the incidence of CHDs in France using the PMSI database. Its aim was not to replace the registries but to study the CHD diagnoses in France using another reference system to increase its completeness.

Studies suggest that the PMSI database is an appropriate data source for epidemiological studies [22–26]. Our methodology using the PMSI database seems correct because we found the same incidences as those reported in the literature [2, 4, 16, 17]. Therefore, a comparison between populations with CHD and those without congenital malformations is legitimate. We excluded children with other congenital malformations from the reference population to avoid confounding factors between the data studied. It is important to note that the number of children varied according to the secondary criteria studied, because information was not always available.

The PMSI database provided an exhaustive list of CHD diagnoses in France, as coding is compulsory and is carried out at the time of diagnosis. This would not have been possible with registries [18]. The population studied was large, increasing the relevance of the comparison

Table 2. Associations between congenital heart defect diagnoses in metropolitan France from 2013 to 2022 in the PMSI-MCO (French Medical Information System Program in Medicine, Surgery and Obstetrics) database.

First ICD-10 code		Second ICD-10 code		Number of patients	Percentage of patients
Q203	Discordant ventriculoarterial connection	**Q201**	Double outlet right ventricle	349	0.42%
Q203	Discordant ventriculoarterial connection	**Q202**	Double outlet left ventricle	42	0.05%
Q203	Discordant ventriculoarterial connection	**Q210**	Ventricular septal defect	1,221	1.46%
Q203	Discordant ventriculoarterial connection	**Q251**	Coarctation of aorta	276	0.33%
Q203	Discordant ventriculoarterial connection	**Q255**	Atresia of pulmonary artery	86	0.10%
Q203	Discordant ventriculoarterial connection	**Q256**	Stenosis of pulmonary artery	281	0.34%
Q210	Ventricular septal defect	**Q211**	Atrial septal defect	5,073	6.05%
Q210	Ventricular septal defect	**Q220**	Pulmonary valve atresia	442	0.53%
Q210	Ventricular septal defect	**Q251**	Coarctation of aorta	1,455	1.73%
Q210	Ventricular septal defect	**Q255**	Atresia of pulmonary artery	443	0.53%
Q213	Tetralogy of Fallot	**Q251**	Coarctation of aorta	16	0.02%
Q220	Pulmonary valve atresia	**Q224**	Congenital tricuspid stenosis	107	0.13%
Q220	Pulmonary valve atresia	**Q225**	Ebstein anomaly	21	0.03%
Q221	Congenital pulmonary valve stenosis	**Q224**	Congenital tricuspid stenosis	59	0.07%
Q221	Congenital pulmonary valve stenosis	**Q225**	Ebstein anomaly	12	0.01%
Q220	Pulmonary valve atresia	**Q224**	Congenital tricuspid stenosis	143	0.17%
Q220	Pulmonary valve atresia	**Q225**	Ebstein anomaly	71	0.08%
Q221	Congenital pulmonary valve stenosis	**Q224**	Congenital tricuspid stenosis	1,455	1.73%
Q221	Congenital pulmonary valve stenosis	**Q225**	Ebstein anomaly	212	0.25%
Q230	Congenital stenosis of aortic valve	**Q232**	Congenital mitral stenosis	89	0.11%
Q230	Congenital stenosis of aortic valve	**Q233**	Congenital mitral insufficiency	79	0.09%
Q251	Coarctation of aorta	**Q210**	Ventricular septal defect	12	0.01%
Q251	Coarctation of aorta	**Q232**	Congenital mitral stenosis	56	0.07%
Q251	Coarctation of aorta	**Q233**	Congenital mitral insufficiency	26	0.03%
Q252	Atresia of aorta	**Q232**	Congenital mitral stenosis	81	0.10%
Q252	Atresia of aorta	**Q233**	Congenital mitral insufficiency	185	0.22%
Q253	Stenosis of aorta	**Q232**	Congenital mitral stenosis	44	0.05%
Q253	Stenosis of aorta	**Q233**	Congenital mitral insufficiency	349	0.42%
Q262	Total anomalous pulmonary venous connection	**Q210**	Ventricular septal defect	42	0.05%
Q262	Total anomalous pulmonary venous connection	**Q211**	Atrial septal defect	1,221	1.46%
Q262	Total anomalous pulmonary venous connection	**Q212**	Atrioventricular septal defect	276	0.33%

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between the CHD and unaffected populations on numerous criteria, which the PMSI database also makes possible.

However, unlike registries, what we gained in exhaustiveness may be lost in diagnostic precision. ICD-10 codes are not very precise (e.g., Q24.9 is "congenital malformation of the heart, unspecified"). The PMSI database is also at risk of coding errors when not carried out by specialists or by poorly trained healthcare professionals, albeit improving [25, 28, 36]. ICD-10 coding is compulsory; however, some ICD-10 codes have no impact on the cost of hospital stays and thus may not be coded. We included children under 3 years of age to limit incomplete data. The PMSI database does not allow searching for more than 10 years back in time, therefore if we had included older children or even adults, recovering the data would not have been possible. This should not have decreased our exhaustiveness because CHDs are diagnosed early in a child's life and even more so if they are severe [4]. We chose the place of diagnosis and not the place of birth or residence to establish a CHD diagnosis in France. This choice appeared to have the lowest risk of child misallocation. We were unable to distinguish between prenatal and postnatal CHD diagnoses.

Table 3. Frequency of perinatal data between children with congenital heart defects and children without congenital malformation in metropolitan France from 2013 to 2022.

Studied factor			Patients with congenital heart defects		Patients without congenital malformation		d
Number/percentage of patients			83,879	100.00%	7,218,952	100.00%	-
Age at diagnosis (month)		[0–1]	66,687	79.50%	-	-	-
		[1–36]	17,192	20.50%	-	-	-
Death (days of life)		N	6,282	7.49%	49,308	0.68%	0.59
		≤ 30	4,745	75.53%	46,652	94.61%	
		31–365	1,302	20.73%	1,584	3.21%	
		> 365	235	3.74%	1,072	2.17%	
Palliative care		Yes	1,691	2.02%	2,529	0.04%	0.20
		No	82,188	97.98%	7,216,423	99.96%	
Sex		Male	43,523	51.89%	3,718,349	51.51%	0.01
		Female	40,356	48.11%	3,500,603	48.49%	
Term of birth (gestation week)		< 24	448	0.74%	11,586	0.19%	0.86
		24–36	21,608	35.89%	304,826	5.13%	
		> 36	38,154	63.37%	5,630,301	94.68%	
Birth weight (g)		< 500	284	0.47%	8,718	0.15%	0.78
		500–1999	16,793	27.89%	96,976	1.63%	
		2000–3999	40,019	66.47%	5,419,024	91.13%	
		≥ 4000	3,114	5.17%	421,995	7.10%	
Mother's age at birth (years)		< 18	275	0.52%	23,560	0.41%	0.15
		18–30	26,778	50.41%	2,936,870	51.28%	
		31–39	22,749	42.82%	2,517,843	43.96%	
		≥ 40	3,319	6.25%	248,820	4.34%	
Mother's parity		Primiparity	29,874	56.24%	2,830,423	49.42%	0.14
		Multiparity	23,247	43.76%	2,896,670	50.58%	
Birth mode	Mode of delivery	Cesarean	18,534	34.89%	1,089,582	19.03%	0.36
		Vaginal birth	34,587	65.11%	4,637,511	80.97%	
	Instrumental birth	Yes	4,849	9.13%	645,708	11.27%	0.07
		No	48,272	90.87%	5,081,385	88.73%	
Medically assisted reproduction		Yes	1,013	1.91%	80,990	1.41%	0.04
		No	52,108	98.09%	5,646,103	98.59%	
Perinatal anomalies	P00.0		5,643	6.73%	111,196	1.54%	0.26
	P01.5		7,273	8.67%	88,592	1.23%	0.35
	P05.0		10,713	12.77%	269,632	3.74%	0.33
	P70.0		5,501	6.56%	326,018	4.52%	0.09
	P70.1		1,592	1.90%	39,009	0.54%	0.12
	P96.1		284	0.34%	6,493	0.09%	0.05

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DROM-COM is separate from the metropolitan population because the populations are different and access to diagnostic and care facilities is sometimes more difficult [37]. Overall, we found the same differences between the populations and similar risk factors as those observed in the mainland population.

Comparisons with the literature

The incidences found in this study were fairly identical to those reported in the literature for each type of CHD, particularly TGA, ToF, and CoA [2, 4]. However, we have observed more

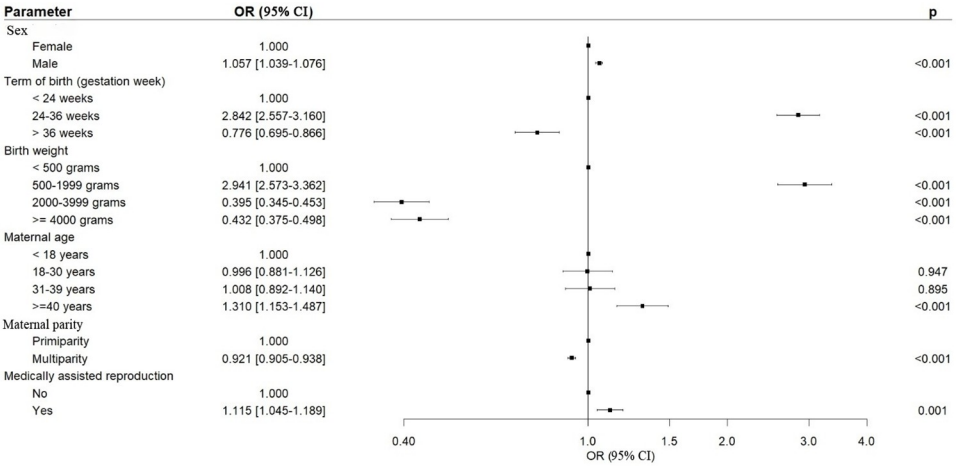

Fig 1. Results of multivariate analysis in metropolitan France. Children with congenital heart defects are compared with the reference population from 2013 to 2022. OR: odds ratio; CI: confidence interval.

https://doi.org/10.1371/journal.pone.0298234.g001

cases of patent ductus arteriosus. This difference could be due to the title of the coding; ductus arteriosus is coded as soon as it is present, particularly in premature babies, where it is extremely common without always impacting the child [5, 38]. However, if all diagnoses of patent ductus arteriosus were excluded (i.e., exclusion in excess), the incidence of CHD would be 8.5%, remaining fairly identical to other studies [3–5].

This partly explains why premature birth and low birth weight, which may be associated with CHD, emerged as risk factors for CHD. However, prematurity appears to be a risk factor for CHD independent of ductus arteriosus. Chu et al. showed an overall increase in the incidence of CHD in children born prematurely between 25 and 32 weeks of gestation, with a high percentage of severe malformations, excluding children with a persistent ductus arteriosus [39].

Much of our data are consistent with what has been described previously. CHDs are a major cause of early death in children [1]. Most diagnoses are made before 1 month of life, including antenatal diagnoses [17]. There were more caesarean sections in cases of CHD, with no differences depending on the type of CHD [40, 41]. MAR is associated with a higher risk of CHD [42]. In twins, there was an increased risk of CHD [43].

Some discrepancies between our data and those published in literatures contribute to the discussion of the inconsistency of the literature. In our study, maternal age $>$ 40 years was a risk factor in multivariate analysis, whereas maternal age $>$ 35 years was sometimes described as a risk factor but not always [11, 29, 44, 45]. Similarly, male individuals were slightly more at risk of CHD in our study, which is consistent with the results of some studies but not others [11, 45–47].

Some of the associations described were either absent or weak. We observed fewer chromosomal abnormalities in children with CHD; however, they remained more numerous than those in the general population [48, 49]. One explanation could be the choice of using ICD-10 codes Q90 to Q99, which does not include all chromosomal and genetic abnormalities but is the easiest to research. This deviation could also be due to the lack of precision in the ICD-10 codes. Similarly, maternal diabetes did not appear to be a risk factor for CHD in our study; however, we only studied diabetes declared during pregnancy, unlike other authors [50].

According to our results, there were no excess mortality in cases of TGA, ToF, or CoA when these were considered serious CHDs, contrary to what has been previously described

[51–53]. This may be explained by improved diagnosis and management of these diseases, which have become standardized.

Contrary to our study, in which multiparity appeared to be protective, Feng et al. showed in their meta-analysis an increased risk of CHD in repeated pregnancies. However, their results were affected by the inclusion of heterogeneous studies and showed an absence of statistical difference when directly comparing primiparous and multiparous women [54].

Improved data collection

The accuracy of the PMSI database could be improved using the ICD– 11th Revision published in 2018 by the WHO, which codes CHDs using a simplified version of the International Pediatric and Congenital Cardiac Code [55, 56]. However, this precise CHD classification has not yet been applied in France.

It seems worthwhile to use the data from the PMSI to feed the registers. Despite these limitations, registers remain a valid solution that avoids most coding accuracy problems [18]. The database already exists and is classified into most registries. In a French study led by the HAS on registers, it was suggested that existing registers should work together more closely to populate a common database rather than setting up a single register (which would incur more cost and human resources and would lack proximity).

Conclusions

The incidence of CHDs in metropolitan France from 2013 to 2022 is 10.7 per 1,000 births, according to the PMSI database. The PMSI database can be used in conjunction with registries to establish the most complete epidemiology of CHDs in France. CHDs are more frequent in cases of prematurity, twinning, primiparity, male sex, and maternal age of $>$ 40 years.

Supporting information

S1 Table. Incidence of congenital heart defect in non-metropolitan France from 2013 to 2022 in the PMSI-MCO (French Medical Information System Program in Medicine, Surgery and Obstetrics) database according to the ICD-10 (International Statistical Classification of Diseases– 10th Revision).
(DOCX)

S2 Table. Frequency of perinatal data between children with congenital heart defects and children without congenital malformation in non-metropolitan France from 2013 to 2022.
(DOCX)

S1 Fig. Results of multivariate analysis in non metropolitan France. Children with congenital heart defects are compared with the reference population from 2013 to 2022. OR: odds ratio; CI: confidence interval.
(TIF)

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Writing – review & editing: Gurvan Bourdon, Xavier Lenne, François Godart, Laurent Storme, Didier Theis, Damien Subtil, Amelie Bruandet, Thameur Rakza.

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