

Algorithms to identify major congenital malformations in routinely collected healthcare data: A systematic review

Drug Safety

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Supplemental Table 4. Algorithms for MCM among regional or national registers, 2010-2025								
Author Year	Country	Data source name	Case ascertainment denominator	Timing of MCM assessment	Algorithm rules	Coding system	Code location in manuscript	Calculated prevalence of the MCM in the unexposed or general population
Cesta, 2024 [1]	Finland Iceland Norway Sweden	MBR, NPR, CMR	Singleton live births	First 12 months of life	≥1 inpatient code or ≥2 outpatient care codes on different dates	ICD9 and 10; ICD9A and 10 in Finland	Supplemental Table 3	3.8%
Karlsson, 2024 [2]	Denmark, Finland, Sweden	MCR, NPR, CDR, CMR	Live and stillbirths	Not specified	≥1 code	ICD-10	Supplementary table 3b	4.6%
Rissmann, 2023 [3]	Denmark, Finland, Italy, UK, Spain, Netherlands, Norway, Malta	CMR	Live births	Birth up to 10 year of life	≥1 code	ICD-9 and ICD-10	Online supplemental appendix C	Not specified
Bröms 2023 [4]	Denmark, Iceland, Norway, Sweden	MBR and CDR	Singleton live births	First 12 months of life (Denmark, Iceland, Sweden); first 3	≥1 inpatient code or ≥2 outpatient care codes on different dates	ICD-10	Methods, Supplemental Table 1	3.7%

				months of life (Norway)				
Cohen, 2023 [5]	Denmark Finland Iceland Norway Sweden	MBR, NPR, CMR, CDR	Pregnancies	First 12 months of life	Finland, only validated diagnoses from the Finnish Register of Congenital Malformations. Denmark, Iceland, Norway, and Sweden: ≥2 diagnosis codes from the same subgroup recorded on separate visit dates if the MCM was only diagnosed in outpatient specialist care.	ICD-10 (Denmark, Iceland, Norway, Sweden) ICD-9A (Finland)	Supplementary Material – Table S1	3.0%
Huybrechts, 2022 [6]	Denmark, Finland, Iceland, Norway, Sweden	MBR and CDR in Denmark, Iceland, Norway, and Sweden; CMR in Finland	Singleton live births	First 12 months of life	≥1 inpatient code or ≥2 outpatient care codes on different dates	ICD-10 and ICD-9A (Finnish Register of Congenital Anomalies)	Supplemental Online Table 2 and Table 3	2.7%
Huybrechts, 2018 [7]	Denmark, Finland, Iceland, Norway, Sweden	MBR, NPR, and CDR in Denmark, Iceland, Norway, and Sweden; CMR in Finland	Singleton live births	First 12 months of life except in Norway (first 3 months of life)	≥1 code	ICD-9 and ICD-10	Supplemental Material	3.8%
Furu, 2015 [8]	Denmark, Finland, Iceland, Norway, and Sweden	MBR, NPR, CMR	Singleton live births	First 12 months of life	≥1 code	ICD-9-CM and ICD-10	Appendix 1	3.2%
Garvik, 2025 [9]	Denmark	NPR	Singleton live births	First 12 months of life	≥1 code	ICD-10	Methods, Table S1	3.7%
Chatwin, 2025 [10]	Denmark	MBR	Live births	First 12 months of life	≥1 code	ICD-10	Methods	Not reported
Kim, 2024 [11]	Denmark	NPR	Singleton live births	Not specified	≥1 code	ICD-8 and ICD-10	Supplementary eTable 2	Not reported
Christensen, 2024 [12]	Denmark	NPR, CDR	Singleton live births	First 12 months of life	≥1 code	ICD-10	Methods/eTable 2	3.6%
Andersen, 2024 [13]	Denmark	NPR	Singleton live births	First 12 months of life	≥1 code	ICD-10	Table S1	No unexposed group
Belza, 2024 [14]	Denmark	MBR, NPR	Live births	Birth	≥1 code	ICD-10	Table S2	Not reported

Jølving, 2023 [15]	Denmark	NPR	Singleton live births	First 12 months of life	≥1 code	ICD-10	Supplementary Table S2	Not reported
Liu, 2023 [16]	Denmark	NPR, Fetal Medicine Database	All clinically recognized singleton pregnancies with a fetus alive at the nuchal scan from gestational week 11	Pregnancy through first 12 months of life	≥1 code	ICD-10	Methods	5.1%
Sorensen, 2022 [17]	Denmark	MBR	Live births	First 12 months of life	≥1 code	ICD-10	Appendix 2	3.8%
Kofoed, 2021 [18]	Denmark	NPR, MBR	Live born singleton infants	First 12 months of life	≥1 code	ICD-8, ICD-10	Methods	Not reported
Andersson, 2021 [19]	Denmark	NPR, MBR	Live births (Sensitivity analyses singleton infants)	First 12 months of life	≥1 code	ICD-10	Supplement page 2	3.3%
Andersson, 2021 [20]	Denmark	NPR, MBR	Live births (Sensitivity analyses singleton infants)	First 12 months of life	≥1 code	ICD-11	Supplement page 1	3.7%
Zöllner, 2021 [21]	Denmark Sweden	NPR, MBR, and other registries	Live births	First 12 months of life	≥1 code	ICD-10	Methods and S1 Tables	3.9%
Skajaa, 2019 [22]	Denmark	NPR, MBR	Live birth	First 12 months of life	≥1 code	ICD-10	Table e1	3.1%
Yang, 2019 [23]	Denmark	NPR	Live born singleton infants	First 12 months of life	≥1 code	ICD-10	Supplement Table S1	10.0%
Pedersen, 2019 [24]	Denmark Sweden	MBR, NPR, CDR	live births	First 12 months of life	≥1 code	ICD-10	Appendix S1	4.2%
Feenstra, 2019 [25]	Denmark	NPR	Live born singleton infants	First 12 months of life	≥1 code	ICD-8, ICD-10	Methods	Not reported
Andersen 2019 [26]	Denmark	NPR	Live births	First 12 months of life	≥1 code	ICD-10	Methods	6.8%
Cohen 2018 [27]	Denmark	NPR	Singleton live births	First 12 months of life	≥1 code	ICD-8, ICD-10	Supplement eTable1	2.1%
Nørgård, 2017 [28]	Denmark	NPR, MBR	Live born singleton infants	NS	≥1 code	ICD-10	Methods	4.8%
Momen, 2017 [29]	Denmark	NPR	Births (live and/or stillbirth)	First 12 months of life	≥1 code	ICD-8, ICD-10	Methods	4.5%

Winter 2017 [30]	Denmark	MBR	Singleton live births	First 12 months of life	≥1 code	ICD-10	Methods	4.8%
Scheller 2017 [31]	Denmark	NPR	Live births	First 12 months of life	≥1 code	ICD-10	Supplementary Appendix	3.3%
Berlac 2017 [32]	Denmark	NPR	Births	Not specified	Not specified	ICD-10, Nordic Classification of Surgical Procedures	Supplementary Material, Table 2S	5.4%
Cohen 2016 [33]	Denmark	NPR	Singleton live births	First 12 months of life	≥1 code	ICD-8, ICD-10	eAppendix	2.2%
Sun, 2016 [34]	Denmark	NPR	Live born singleton infants	First 12 months of life	≥1 code	ICD-8, ICD-10	Methods	5.4%
Bröms, 2016 [35]	Denmark, Sweden	NPR	Births	First 12 months of life	≥1 code	ICD-10	Supplement Table 2	4.2%
Boyd, 2015 [36]	Denmark	NPR, MBR	Live or stillbirths	NS	≥1 code	ICD-8, ICD-10	Supplemental Material S2 File	2.7%
Tougaard, 2015 [37]	Denmark	NPR	Singleton live births	First 12 months of life	≥1 code	ICD-8, ICD-10	Supplement Table B, Table C	3.7%
Larsen 2015 [38]	Denmark	MBR	Singleton births	At birth	≥1 code	ICD-10	Methods	No unexposed population
Sun, 2014 [39]	Denmark	NPR	Live born singleton infants	First 12 months of life	≥1 code	ICD-10	Methods	NR
Larsen, 2014 [40]	Denmark	NPR	Live born singleton infants	At birth	≥1 code	ICD-10	Methods	5%
Julsgaard 2014 [41]	Denmark	NPR	Live born singleton infants	First 12 months of life	≥1 code	ICD-10	Methods	6%
Bjørn 2014 [42]	Denmark	NPR	Singleton live births	First 12 months of life	≥1 code	ICD-8, ICD-10	Appendix	4.3%
Pasternak, 2013 [43]	Denmark	NPR	Live born singleton infants (Sensitivity analysis abortions for medical reasons and stillbirth)	First 12 months of life	≥1 code	ICD-10	eTable 1	2.7%
Mølgaard-Nielsen, 2013 [44]	Denmark	NPR	Live born singleton infants	First 12 months of life	≥1 code	ICD-10	Table S1	2.6%
Pasternak, 2013 [45]	Denmark	NPR	Live born singleton infants	First 12 months of life	≥1 code	ICD-10	Table S1	2.9%
Andersen, 2013 [46]	Denmark	NPR	Births (live and/or still birth)	First 12 months of life	≥1 code	ICD-8, ICD-10	Supplement Table 1	5.7%
Krogh, 2012 [47]	Denmark	NPR	Singleton live births	First 12 months of life	≥1 code	ICD-10	Methods	Not reported

Hjortebjerg, 2012 [48]	Denmark	NPR	Live born singleton infants	First 12 months of life	≥1 code	ICD-10	Supplementary Material File 1	5.5%
Fedder 2012 [49]	Denmark	NPR	All births	First 12 months of life	≥1 code	ICD-10	Methods	No unexposed population
Mølgaard-Nielsen, 2011 [50]	Denmark	NPR	Live births	First 12 months of life	≥1 code	ICD-10	Supplement eMethods	2.4%
Morales-Suárez-Varela, 2011 [51]	Denmark	NPR, MBR	Live born singleton infants	First 12 months of life	≥1 code	ICD-10	Methods	3.9%
Stephansson 2011 [52]	Denmark Sweden	MBR, NPR	Singleton live births and stillbirths	First 12 months of life	≥1 code	ICD-9, ICD-10	Methods	3.1%
Pasternak, 2010 [53]	Denmark	NPR	Live births	First 12 months of life	≥1 code	ICD-10	Supplement Methods	2.6%
Morales-Suárez-Varela, 2010 [54]	Denmark	NPR, MBR	Live born singleton infants	First 12 months of life.	≥1 code	ICD-10	Methods	4.1%
Pinborg, 2010 [55]	Denmark	NPR	Live born singleton infants	First 12 months of life	≥1 code	ICD-10	Methods	6.3%
Pasternak 2010 [56]	Denmark	NPR	Live births	First 12 months of life	≥1 code	ICD-10	eAppendix	2.4%
Nørgaard, 2010 [57]	Denmark, Sweden	MBR, HDR	Singleton live births	First 12 months of life	Not specified	ICD-9, ICD-10	Appendix	3.0%
Elfving, 2024 [58]	Finland	CMR	Pregnancies ≥22 weeks gestation through 1 year olds	Pregnancy through 1 year of life	≥1 code	ICD-10	Methods, Table 3	4.3%
Danner, 2023 [59]	Finland	HDR	Patients <2 years of age with congenital hypothyroidism and controls	Birth through end of follow-up	≥1 code	ICD-10	Methods	7.4%
Brand, 2022 [60]	Finland	MBR, CMR	Singleton live births	First 12 months of life	≥1 code	ICD-9, ICD-10	Supplemental Table S3	4.9%
Ellfolk, 2021 [61]	Finland	MBR, CMR	Singleton live births, stillbirths or elective terminations	First 12 months of life	≥1 code	ICD-9	Methods	4.4%
Macharey, 2020 [62]	Finland	MBR, CMR	Singleton live births	First 12 months of life	Not specified	ICD-10	Methods	3.6%
Kuitunen, 2020 [63]	Finland	MBR, CMR	Live births and stillbirths	Pregnancy and at birth	Not specified	ICD-10	Results Table 2	3.6%
Hvide, 2021 [64]	Norway	MBR	Singleton births	At birth	≥1 code	ICD-8	Appendix Table 4	2.5-3.5%
Engeland, 2013 [65]	Norway	MBR	Births	Not specified	Not specified	ICD-10	Methods	2.6%

Fernández de la Cruz, 2023 [66]	Sweden, Canada	MBR, British Columbia Perinatal Database Registry	Live and stillbirths	Pregnancy through first month of life	≥1 code	ICD-9-CM and ICD-10-CM	eTables 1 and 2 in Supplement 1	Sweden: 4.1%, Canada: 3.0%
Nguyen, 2025 [67]	Sweden	MBR, NPR	Live births	First 12 months of life	≥1 ICD code from the MBR or ≥1 ICD-coded hospitalization or ≥2 ICD-coded outpatient specialist visits of the same MCM subgroup	ICD-10	Table S2	3.4%
Segovia, 2024 [68]	Sweden	MBR	Live births	At birth, 90 days, 1 year, 2 years, and 3 years after birth	≥1 code	ICD-10	Table S1	1.9% at birth, 3.1% at 90 days, and 3.9%, 4.4% and 4.7% at 1, 2 and 3 years after birth
Nakitanda, 2024 [69]	Sweden	NPR, CDR	Singleton live births	First 12 months of life	≥1 code	ICD-10	Methods and eTable 2	3.9%
Zylberberg, 2023 [70]	Sweden	MBR	Live births	Birth	≥1 code	ICD-10	Supplementary Tables	3.6%
Ginström Ernstad, 2023 [71]	Sweden	IVF registers, National Quality Register for Assisted Reproduction, MBR, CDR	Singleton live births	First 12 months of life	≥1 code	ICD-9 and ICD-10	Methods	At birth: 2.0%; Up to 1 year 4.8%
Sharma, 2023 [72]	Sweden	NPR, CDR	Singleton live births	First 12 months of life	≥1 code	ICD-9, ICD-10	Supplementary Table 3	5.6%
Mitselou, 2022 [73]	Sweden	MBR, NPR	Singleton live births	At birth	≥1 code	ICD-10	Methods and Online Repository	3.9%
Köcher, 2020 [74]	Sweden	MBR, NPR	Singleton births	First 12 months of life	≥1 code	ICD-10	Supplementary Information Table S1	3.7%
Tomson, 2020 [75]	Sweden	MBR, NPR	Singleton live births	First 12 months of life	≥1 code	ICD-9, ICD-10	Supplement Table S1	4.3%
Ji, 2018 [76]	Sweden	MBR, HDR	Singleton live births	Other	≥1 code	ICD-9, ICD-10	Methods	7.7%
Ludvigsson, 2018 [77]	Sweden	NPR, CDR	Singleton live births	First 12 months of life	≥1 code	ICD-10	Supplementary Appendix eTable 4	Not reported
Andersen, 2017 [78]	Sweden	NPR	Live births	First 12 months of life	≥1 main or additional code	ICD-10	Methods	8%
Ludvigsson, 2017 [79]	Sweden	MBR, NPR	Live births and still births	First 12 months of life	≥1 code	ICD-9, ICD-10	Supplementary Material	3.5%
Persson, 2017 [80]	Sweden	MBR, NPR, CDR	Singleton live births	First 12 months of life	≥1 code	ICD-10	Supplementary Web Appendix, eTable 2 and eTable 3	3.5%
Sabeti Rad, 2017 [81]	Sweden	MBR, BDR, HDR	Live births	First 12 months of life	≥1 code	ICD-9, ICD-10	Supporting information, Table S2	Not reported

Razaz, 2017 [82]	Sweden	MBR, NPR	Singleton births	First 12 months of life	≥1 code	ICD-9, ICD-10	Supplementary Online Content - eTable2	3.3%
Johansson 2015 [83]	Sweden	MBR, NPR	Singleton births	First 12 months of life	≥1 code	ICD-10	Supplementary Appendix Table S3	3.5%
Zugna 2014 [84]	Sweden	MBR, NPR, CMR	Singleton births	Not specified	≥1 code	ICD-8, ICD-9, ICD-10	Supplementary Table 2	5.1%
Ludvigsson 2014 [85]	Sweden	MBR	Singleton births	Not specified	≥1 code	ICD-9, ICD-10	Methods	3.6%
Hellerstedt 2013 [86]	Sweden	MBR	First-born singleton live births	Not specified	Not specified	ICD-9, ICD-10	Methods	4.5%
Wingren 2012 [87]	Sweden	MBR, NPR	Singleton birth children	First 12 months of life	≥1 code	ICD-9	Methods	Not reported
Svensson 2011 [88]	Sweden	MBR	Singleton births	At birth	≥1 code	ICD-10	Methods	5.5%
Norstedt Wikner 2011 [89]	Sweden	MBR, NPR, CMR	Births	Not specified	≥1 code	ICD-9, ICD-10	Materials & Methods	4.7%
Björnsdottir 2010 [90]	Sweden	MBR, NPR	Singleton and multiple births	Not specified	≥1 code	ICD-8, ICD-9, ICD-10	Supplement Appendix	4.3%
Blomberg 2010 [91]	Sweden	MBR, NPR, CMR	Still births and live births	Not specified	≥1 code	ICD-9, ICD-10	Methods	3.2%
Källén 2010 [92]	Sweden	MBR, CMR, HDR	Births	First 12 months of life	≥1 code	ICD10	Methods	4.4%
Reis 2010 [93]	Sweden	MBR, CMR, HDR	Births	Not specified	≥1 code with specific exclusions	ICD9, ICD10	Methods	4.3%
Luke 2022 [94]	Canada	BCPDR, Better Outcomes Registry & Network Ontario, Perinatal Program Newfoundland and Labrador	Singleton live births and stillbirths	At birth	Not specified	ICD-10-CA	Supplemental Table 1	0.6%
Abdullah 2020 [95]	Canada	Ontario's Better Outcomes Registry and Network (BORN) database	Singleton live births	First 12 months of life	≥1 code	ICD-9, ICD-10	Supplementary Table E2	No unexposed population
Tsao 2019 [96]	Canada	BCPDR, BCDAD, BCMSP	Live births	First 12 months of life	≥1 anomaly recorded in the BCPDR; or ≥2 inpatient records in the BCDAD with diagnostic codes for an anomaly; or ≥3 outpatient visits in the BCMSP database with diagnostic codes for an anomaly	ICD-9-CA, ICD-10-CA	Methods	6%

Schummers 2018 [97]	Canada	BCPDR and Vital Statistics Data	Not specified	At birth	Not specified	ICD-10-CA	Supplementary Materials	Not reported
Dimich-Ward 2013 [98]	Canada	Cohort of Registered Nurses in British Columbia linked with British Columbia Vital Statistics Agency and BCHSR	Singleton live births and stillbirths	First 12 months of life	Not specified	ICD-9, ICD-10	Methods	8%
Teschke 2011 [99]	Canada	BCHSR	Singleton live births	First 12 months of life	Not specified	ICD-9, ICD-10	Methods	7% among live births; 7.2% among live and still births
Arbour 2010 [100]	Canada	Cohort of Registered Nurses in British Columbia linked with BCHSR	Live births and stillbirths	First 12 months of life	Not specified	ICD-9	Methods	6.7%

BCDAD: British Columbia Discharge Abstract Data, BCHSR: British Columbia Health Status Registry, BCMSP: British Columbia Medical Services Plan, BCPDR: British Columbia Perinatal Data Registry, BDR: Birth Defects Register, CDR: Causes of Death Register, CM: Congenital malformation, CMR: Congenital Malformations Register, HDR: Hospital Discharge Register, MBR: Medical Birth Registry, NPR: National Patient Registry, PDR: Prescribed Drug Register, NS: Not specified,

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