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ORIGINAL ARTICLE

Higher risk of cerebral palsy, seizures/epilepsy, visual- and hearing impairments, cancer, injury and child abuse in children with congenital anomalies: Data from the EUROlinkCAT study

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Abstract

Aim: The aim is to examine the risk of cerebral palsy, seizures/epilepsy, visual- and hearing impairments, cancer, injury/poisoning and child abuse in children with and without a congenital anomaly up to age 5 and 10 years.

Methods: This is a population-based data linkage cohort study linking information from the European Surveillance of Congenital Anomalies network (EUROCAT) and birth registries to hospital discharge databases. We included 91 504 live born children with major congenital anomalies born from 1995 to 2014 from nine EUROCAT registries in five countries and 1 960 727 live born children without congenital anomalies (reference children). Prevalence and relative risk (RR) were estimated for each of the co-morbidities using Kaplan–Meier survival estimates.

Results: Children with congenital anomalies had higher risks of the co-morbidities than reference children. The prevalences in the reference children were generally

Abbreviations: CI, confidence intervals; EUROCAT, the European Surveillance of Congenital Anomalies network; EUROlinkCAT, Establishing a linked European Cohort of Children with Congenital Anomalies Project; ICD, International Classification of Diseases; RR, relative risk.

very low. The RR was 13.8 (95% CI 12.5–15.1) for cerebral palsy, 2.5 (95% CI 2.4–2.6) for seizures/epilepsy, 40.8 (95% CI 33.2–50.2) for visual impairments, 10.0 (95% CI 9.2–10.9) for hearing loss, 3.6 (95% CI 3.2–4.2) for cancer, 1.5 (95% CI 1.4–1.5) for injuries/poisoning and 2.4 (95% CI 1.7–3.4) for child abuse.

Conclusion: Children with congenital anomalies were more likely to be diagnosed with the specified co-morbidities compared to reference children.

KEYWORDS
cerebral palsy, congenital anomalies, epilepsy, injuries and poisoning

1 | INTRODUCTION

Congenital anomalies are structural defects that occur during intrauterine life, thus referring to defects that exist before birth.[1] Congenital anomalies represent a continuum, with severity ranging from the less severe anomalies with minimal clinical significance to severe malformations incompatible with life. In Europe, it has been estimated that congenital anomalies account for 26% of all infant deaths, 17% of deaths of children aged 1–4 years and 9% of deaths of children aged 5–9 years.[2] As such they are a major contributor to childhood mortality. Improvements in survival may be attributed to optimised surgical management strategies and pharmacological treatment.[3–5] However, a similar decrease in mortality observed in the background population suggests that multiple factors impact this trend.[2] With research focused predominantly on mortality, less attention has been given to the morbidity associated with congenital anomalies.

Population-based studies have shown that children with congenital anomalies are more frequently hospitalised and that, on average, they spend more time in hospital than children without congenital anomalies.[6] Similarly, these children were prescribed more cardiovascular medication[7] and were 80 times more likely to receive a gastrostomy feeding tube than children without congenital anomalies.[8] A higher risk of cancer has been consistently found in children with congenital anomalies, and especially in children with chromosomal anomalies.[9–12] Congenital anomalies have been reported to be a leading cause for severe childhood visual impairment in high-income countries in Europe[13] and congenital cerebral anomalies have been reported as risk factors for seizures and epilepsy.[14] Cerebral palsy serves as a comprehensive descriptor for non-progressive conditions involving motor impairments, and about 12%–32% of children diagnosed with cerebral palsy have a congenital anomaly.[15]

In addition to the physical health challenges associated with congenital anomalies, it is crucial to consider the broader psychosocial impacts these conditions may have on affected children and their families. Among these, the potential for increased risk of child abuse is a particularly sensitive yet important area of investigation. Families of children with congenital anomalies may experience higher levels of stress, financial strain, and caregiving burden. These factors can, unfortunately, increase the risk of familial tension and conflict, potentially leading to higher instances of child abuse.

Key notes

- This study addresses the gap in understanding the full spectrum of health challenges faced by children with congenital anomalies.
- Findings revealed significantly higher risks of cerebral palsy, seizures/epilepsy, visual and hearing impairments, cancer, injury/poisoning, and child abuse in children with congenital anomalies compared to their peers.
- The results underscore the need for comprehensive healthcare strategies that encompass both medical and psychosocial support for these children and their families.

Previous studies on co-morbidities were often based on non-representative samples, such as children with congenital anomalies referred for surgery at a tertiary hospital. Also, previous research has often been focused on individual defects only, for example, hypoplastic left heart syndrome or gastroschisis, or broader categories from a single organ system, for example, cardiac or gastrointestinal defects.

There is currently limited data from population-based studies on co-morbidities in cohorts of children with congenital anomalies, which is necessary in order to evaluate the total burden of disease. In this European multicentre study, we aimed to examine the following co-morbidities in children with major congenital anomalies as a whole up to 10 years of age in a European population-based setting: cerebral palsy, seizures/epilepsy, visual- and hearing impairments, cancer, injuries/poisonings and child abuse.

2 | METHODS

2.1 | Study design and study population

This is a European, population-based data-linkage cohort study involving registries from the European surveillance of congenital anomalies network (EUROCAT). The EUROCAT network is a consortium of population-based registries for the surveillance of congenital

TABLE 1 The numbers of children with congenital anomalies (EUROCAT children) and without congenital anomalies (reference children) according to EUROCAT region and age group.

EUROCAT registry	Birth years included	Number of children		Included in analysis of 0–4 years	Included in analysis of 0–9 years
		EUROCAT children	Reference children		
Denmark, Funen	1995–2014	2423	100 748	Yes	Yes
Finland	1997–2014	38 324	911 679	Yes	Yes
Italy, Emilia-Romagna	2008–2014	5381	223 995	Yes	No
Italy, Tuscany	2005–2014	4225	23 503	Yes	No
Spain, Valencian Region	2010–2014	4260	168 563	Yes	No
UK, Wales	1998–2014	17 448	531 784	Yes	Yes
UK, East Midlands & South Yorkshire	2003–2012	11 278	Data for reference children not available	Yes	No
UK, Thames Valley	2005–2013	3845		Yes	No
UK, Wessex	2004–2014	4320		Yes	No
Total		91 504	1 960 272		

anomalies, which covers a wide geographical area across Europe. Each registry collects comprehensive data on all live births, foetal deaths from 20 weeks of gestation, and terminations of pregnancy for foetal anomaly occurring within a well-defined geographic area, for example, a region or a whole country. This ensures that the registry contains data on all children born with congenital anomalies in their area. The registries adhere to a standardised protocol for data collection and classification of congenital anomalies, which ensures consistency and comparability of data across different regions. In EUROCAT, information is mainly collected up to a baby's first year of life, and very few registries collect information on children without congenital anomalies.

In the project Establishing a linked European Cohort of Children with Congenital Anomalies (EUROlinkCAT), all children registered in the participating EUROCAT registries as well as children without congenital anomalies born in the same period and from the same population covered by each registry (reference children) were included. All children were linked to regional or national databases on mortality, hospital discharge, prescription and educational databases up to age 5 or 10 years.[16]

This study was based on the part of the EUROlinkCAT project where children were linked to information from hospital discharge databases.[17] The necessary data were available from nine EUROCAT regions in five European countries (Table 1). We included all live born children with major congenital anomalies (EUROCAT children) as well as reference children born between 01 January 1995, or the first year of the EUROCAT registry if later, and 31 December 2014, or the last available year if before. The Tuscany registry from Italy included a 10% random sample of the reference population matched based on the child's birth year and sex. Individual-level data on reference children were not available for the three English registries: East Midlands & South Yorkshire, Thames Valley and Wessex.

To identify and include all relevant cases, we linked the records of all EUROCAT and reference children to multiple administrative databases. These databases included not only hospital discharge records but also vital statistics, such as census data and death records, prescription databases and outpatient records. This linkage process was conducted for periods both within and beyond the scope of our study. Children who were successfully matched to any of these databases at any point during or after the study period, including after their 10th birthday, were classified as matched children and included in our study population. Conversely, children who could not be matched to any hospital discharge or other administrative databases, either during or outside the study period, were considered missed linkages and were excluded from our study population. This exclusion criterion was particularly pertinent for children who were recorded in EUROCAT as dying at least 1 day after birth but had no recorded matches in any database. The rationale behind this exclusion was based on the expectation that childhood deaths are generally preceded by hospital admissions, barring exceptional circumstances such as sudden infant death, murder, or accidents. By applying these criteria, we aimed to ensure the completeness and

TABLE 2 Number and prevalence of co-morbidity in EUROCAT children and reference children according to age.

Co-morbidity	0–4 years				0–9 years[a]			
	EUROCAT children N = 91 504		Reference children N = 1 960 272		EUROCAT children N = 58 195		Reference children N = 1 544 211	
	n	Number per 1000[b] (95% CI)	n	Number per 1000[b] (95% CI)	n	Number per 1000[b] (95% CI)	n	Number per 1000[b] (95% CI)
Cerebral palsy	784	10.2 (8.3–12.5)	1187	0.6 (0.5–0.8)	594	14.8 (9.0–23.0)	1289	1.1 (0.8–1.5)
Seizures/epilepsy	4266	56.4 (47.7–66.2)	35 850	21.0 (14.4–29.8)	2943	68.7 (50.1–91.1)	33 439	30.2 (18.1–47.4)
Visual impairments and blindness	408	4.6 (2.4–8.3)	144	0.1 (0.1–0.1)	243	5.9 (1.9–14.9)	186	0.2 (0.1–0.3)
Hearing loss	1229	16.1 (9.3–26)	1784	0.8 (0.4–1.6)	776	16.3 (6.5–34.5)	2851	1.8 (0.4–5.9)
Cancer	293	3.7 (3.2–4.3)	1605	1.0 (0.8–1.2)	216	4.6 (4.0–5.3)	1718	1.4 (1.3–1.6)
Any injury/poisoning	5486	66.8 (48.2–89.4)	76 886	34.3 (18.6–57.6)	4938	121.4 (69.3–189.2)	101 679	87.1 (45.2–146.1)
Child abuse	40	0.5 (0.3–0.8)	393	0.2 (0.1–0.4)	33	0.8 (0.4–1.7)	417	0.4 (0.2–0.8)

[a]Only three registries included for 0–9 years.
[b]1-Kaplan–Meier estimate of the co-morbidity in age period from meta-analysis of all registries.

accuracy of our study cohort, thereby enhancing the reliability of our findings. This has previously been described in detail.[6,17]

2.2 | Congenital anomalies

We included all children with any major congenital anomaly (EUROCAT children) in the registries according to EUROCAT definitions.[18] The EUROCAT children may have isolated or multiple congenital anomalies, where an isolated congenital anomaly were defined as a congenital anomaly in one organ system only and without an associated genetic diagnosis.[19] Results for specific subgroups of isolated congenital anomalies are included in the Supplementary Tables.

2.3 | Data on diagnoses

Individual level data on the EUROCAT children and reference children were linked electronically to routinely collected data on diagnoses in hospital discharge databases. Outpatient visits were not included in this study. Each registry created a data set using a common data model to ensure that all the relevant variables were coded identically. A detailed description of the study methodology, including the linkage methodology and common data model of standardised variables has been published elsewhere.[6,17] Data on diagnoses were included up to the child's 10th birthday or the end of 2015, whichever came earlier, to ensure at least 1 year of follow-up after birth for all children.

For Finland, Funen in Denmark, Tuscany in Italy and the three English regions, the hospital databases covered diagnoses covering the whole country. For Wales, the hospital database covered hospital stays in both Wales and England. For the Valencian Region in Spain and Emilia-Romagna in Italy, the hospital databases covered the same region as the EUROCAT registry. All primary and supplementary or secondary diagnosis codes given at discharge from inpatient hospital admissions were included. In Denmark, Finland, Wales and the three English regions, the diagnosis codes were based on the International Classification of Diseases (ICD) version 10 and in Italy and Spain, the ICD-9-CM version was used.

Seven co-morbidities were included: cerebral palsy, seizures/epilepsy, visual impairments and blindness, hearing loss, cancer, any injury/poisoning and child abuse. See Table S1 for details on ICD codes for each co-morbidity.

2.4 | Statistics

We calculated the proportion of children with congenital anomalies (EUROCAT children) and those without (reference children) who were diagnosed with each co-morbidity in each registry using Kaplan–Meier survival estimates to take into account the varying follow-up times due to censoring at the end of the study,

at emigration or at death. The registry-specific Kaplan–Meier estimates and 95% confidence intervals (CIs) were combined to estimate the overall prevalence of each co-morbidity. The registry-specific CIs were calculated using the ln(−ln(S(*t*))) transformation and the Kaplan–Meier estimates and CIs were combined in a random-effects inverse-variance meta-analysis using the ln(−ln(S(*t*))) transformation. The I^2 statistic was used to assess between-registry heterogeneity. If there were less than 10 children in total with a co-morbidity, the proportion of children with the morbidity was calculated as the total number of children with the morbidity divided by the total number of children, which did not take into account registry or censoring. The CI of this proportion was calculated as a Wilson confidence interval.

We then aimed to determine how much more likely children with a congenital anomaly were diagnosed with certain co-morbidities compared to children without such anomalies. To do this, in each registry the estimated proportions of EUROCAT children who were diagnosed with a co-morbidity was divided by the estimated proportion of reference children who were diagnosed with the same co-morbidity. This estimated the relative risk (RR) of being diagnosed with a co-morbidity in children with an anomaly compared to those without in each registry. A meta-analysis was then performed combining these RRs using the Mantel Haenszel method based on the inverse variance.

The prevalences were estimated in two overlapping age groups; 0–4 years and 0–9 years. Six registries had insufficient data on children after 5 years of age and were not included in the analysis of 0–9 years. RRs were estimated for the age group 0–4 years. Due to restrictions on releasing small numbers, pooled estimates based on less than five children were not provided.

Analyses were performed using Stata statistical software: Release 15 (2017). College Station, TX: StataCorp LLC, USA.

3 | RESULTS

In total, 91 504 EUROCAT children and 1 960 272 reference children were included in the study (Table 1). The linkage success between databases was 97.5% for the EUROCAT children and 95.2% for reference children.

Table 2 shows the prevalence of each of the seven co-morbidities in EUROCAT children and reference children. The prevalence of each co-morbidity was considerably higher in EUROCAT children than in reference children for both age groups. Among EUROCAT children, 10.2/1000 children had a hospital diagnosis of cerebral palsy, 4.6/1000 children had a hospital diagnosis of visual impairments/blindness, and 16.1/1000 children had a hospital diagnosis of hearing loss before age 5 years. Cancer was diagnosed in 3.7/1000 children of EUROCAT children before age 5 years compared to 1/1000 children of the reference children. The proportion with a hospital diagnosis of seizures/epilepsy was twice as high for EUROCAT children compared to reference children (56.4/1000 children compared to 21.0/1000 children). A hospital diagnosis of injury/poisoning in the age group 0–9 years was given to 121.4/1000 children of EUROCAT children and 87.1/1000 children of reference children. The proportion of diagnoses of child abuse was very low for all children and age groups (<1/1000 children), but twice as high for EUROCAT children compared to reference children.

Figure 1 shows the RR of each co-morbidity at ages 0–4 years. The RR was higher for EUROCAT children compared to the reference children for all co-morbidities: 13.8 (95% CI 12.5–15.1) for cerebral palsy, 2.5 (95% CI 2.4–2.6) for seizures/epilepsy, 40.8 (95% CI 33.2–50.2) for visual impairments, 10.0 (95% CI 9.2–10.9) for hearing loss, 3.6 (95% CI 3.2–4.2) for cancer, 1.5 (95% CI 1.4–1.5) for injuries/poisoning and 2.4 (95% CI 1.7–3.4) for child abuse.

There was a considerable degree of between-registry heterogeneity in the prevalence of specific morbidities, apart from cancer, but the magnitude of these differences in prevalence was small when compared to the differences in prevalence between EUROCAT and reference children (Table 2).

Tables S2, S3 and S4 show results for subgroups of specific isolated congenital anomalies. As many anomalies are rare and some of the co-morbidities are rare, only some results were available due to small numbers.

4 | DISCUSSION

We conducted a population-based European study of more than 90 000 children with congenital anomalies (EUROCAT children) and almost 2 million reference children. The prevalence of EUROCAT children with an inpatient hospital diagnosis of the specific co-morbidities was considerably higher than for reference children. The most frequent type of co-morbidity was seizures/epilepsy affecting 56 per 1000 children with congenital anomalies and 21 per 1000 reference children, ages 0–4 years. In general, the RRs for all co-morbidities were significantly higher for children with congenital anomalies than for reference children.

The worldwide prevalence of cerebral palsy, based on 49 studies including children at different ages, mostly around 4–8 years of age,[20] was reported to be 2.1 per 1000 (95% CI 2.0–2.3 per 1000). In our study, the prevalence of reference children with a cerebral palsy diagnosis was 0.6 per 1000 (95% CI 0.5–0.8 per 1000) before age 5 years and 1.1 per 1000 (95% CI 0.8–1.5 per 1000) before age 10 years. For children with congenital anomalies, we found that 10.2 per 1000 (95% CI 8.3–12.5 per 1000) had a hospital diagnosis of cerebral palsy before age 5 years and 14.8 per 1000 (95% CI 9.0–23.0 per 1000) before age 10 years. The very low prevalence for reference children suggests that not all children with cerebral palsy have been hospitalised with an inpatient diagnosis of cerebral palsy and that the results from this study may have underestimated the risk of cerebral palsy.

Febrile seizures are common in small children and affect 20–50 per 1000 children under 5 years of age.[21] This study found that 21 per 1000 (95% CI 14.4–29.8) reference children had a hospital diagnosis of seizures/epilepsy at ages 0–4 years, indicating good

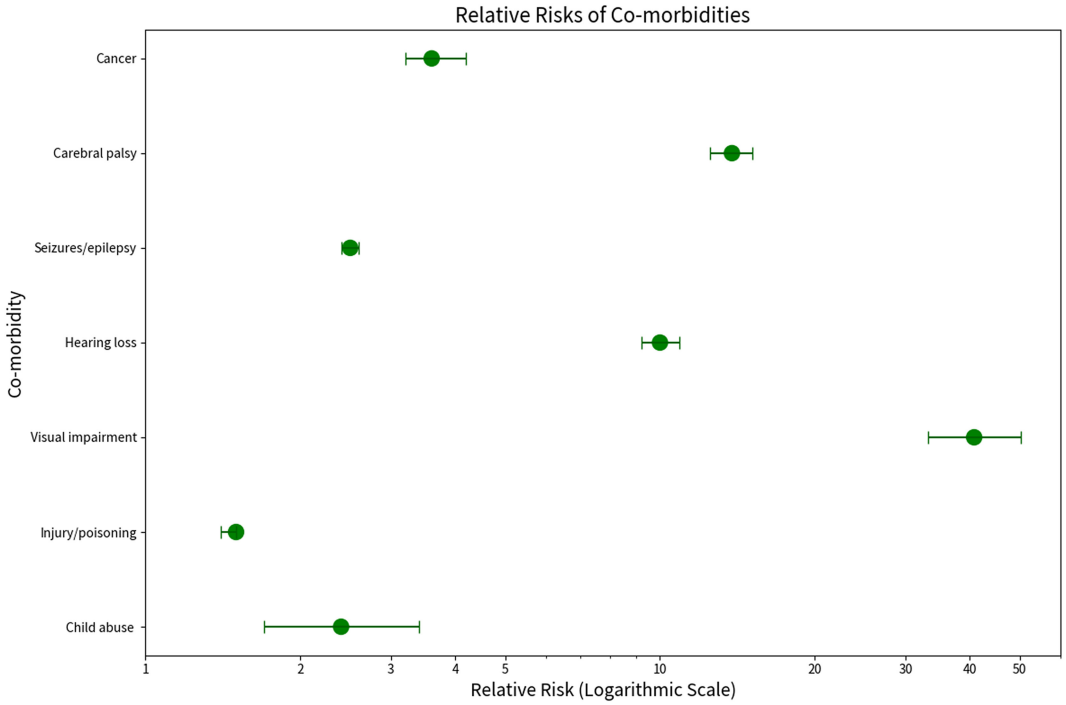

FIGURE 1 Relative risk of each co-morbidity for EUROCAT children compared to reference children in the age group 0–4 years. Estimates are based on data from the six registries with reference children. Numbers in brackets show upper and lower confidence intervals.

reporting of these diagnoses in our study as not all children with febrile seizures are hospitalised. The prevalence among EUROCAT children of a diagnosis of seizures/epilepsy was 56.4 per 1000 (95% CI 47.7–66.2) at ages 0–4 years. A population-based study from Canada showed that congenital cerebral anomalies was a significant risk factor for epilepsy in childhood.[14]

The prevalence of a hospital diagnosis of visual impairments was low for reference children at 0.1 per 1000 (95% CI 0.1–0.1 per 1000) at 0–4 years and 4.6 per 1000 (95% CI 2.4–8.3 per 1000) for the EUROCAT children. The leading cause of visual impairments in young children are optic nerve anomalies and cortical blindness and this explains the high prevalence of visual impairment found in our study for children with congenital hydrocephaly (Table S2).[3,22,23]

Our study showed that 16.1 per 1000 EUROCAT children (95% CI 9.3–26.0 per 1000) had a hospital diagnosis of hearing impairment in both age groups. This indicates that the hearing impairment was diagnosed early in childhood. For reference children the prevalence was 0.8 per 1000 (95% CI 0.4–1.6 per 1000) at 0–4 years and 1.8 per 1000 (95% CI 0.4–5.9 per 1000) at 0–9 years indicating that a higher prevalence of reference children had acquired hearing impairments, that is, increasing prevalence with age. In the United Kingdom, the prevalence of hearing impairment up to age 5 years was found to be 1.33 per 1000 live births, which is comparable to our results.[24]

Despite the large number of children included in our study, we were not able to report results for cancer in many of the included isolated congenital anomaly subgroups due to small numbers. As reviewed in detail by Johnson et al.[9] most case–control studies reported increased relative risks of 2–4.5 for childhood cancer in children with congenital anomalies aligning with our findings (Figure 1).

To our knowledge, no other studies have specifically looked at the risk of accidental injuries or poisoning in children with congenital anomalies. Unintentional injuries are the leading cause of death in children aged 5–14 years in Europe[25] and changes in risk profile for these types of events are therefore of importance. In our study, the number of children with a diagnosis of injury/poisoning was much greater than the other co-morbidities. In both age groups, the relative risk of injury was approximately doubled for children with congenital anomalies. A previous study looked at the association between congenital anomalies and child mortality and found a four-fold increased risk of death from external causes/injuries.[26] Children with congenital anomalies may also be more likely to have an inpatient diagnosis of an injury while a similar injury may just require outpatient treatment for children without congenital anomalies.

The prevalence of children with a hospital diagnosis of child abuse was extremely low for both children with congenital anomalies and reference children, although it was twice as high for EUROCAT children. It is well known that child abuse is under-reported.[27] The actual prevalence is uncertain, but it appears to have been decreasing over the last decades.[28] From our results, it is not possible to tell if the higher prevalence for children with congenital anomalies was because these children were seen at hospital more often and, as a result, there was a higher likelihood of child abuse being picked up, or if there was an actual higher risk for child abuse, for example, due to the increased stress on these parents.

This study showed that the prevalence of all co-morbidities analysed in this study were higher among children with congenital anomalies than reference children. Part of the higher risk for the EUROCAT children may be because children with congenital anomalies were

more often hospitalised[6] and thus were more often examined by health care professionals at hospitals. Due to the descriptive nature of the study, the results should be interpreted as exploratory as we are not able to clarify if the underlying mechanisms are based on common causes or if specific congenital anomalies predisposed the child toward the included measures of co-morbidity.

4.1 | Strengths and limitations

The main strengths of our study included the large population-based cohort of children across five European countries with standardised ascertainment, classification and registration of the congenital anomalies in the EUROCAT registries. Moreover, as part of the EUROlinkCAT study, hospital data were standardised to a common data model and syntax scripts were developed enabling the possibility to combine analytical results. The linkage success was high with 97.5% of the EUROCAT children and 95.2% of the reference children included in the study. An important limitation of this study was the use of data from administrative hospital databases not collected for research purposes. Due to differences in the national and regional health information systems, we were not able to use disease-specific registers, such as cancer registers[29] or registers of visual impairment.[30] Moreover, outpatient data were not available, so we were only able to include diagnoses from in-patient hospital admissions. As a consequence, we have likely underestimated some of the co-morbidities. This was especially true for visual- and hearing impairments, as these children were more likely to be seen in otorhinolaryngology outpatient departments. Though we included more than 90 000 children with congenital anomalies, the statistical precision was limited for specific combinations of congenital anomalies and types of co-morbidities. Moreover, we were not able to publish the prevalence in several congenital anomaly subgroups due to low numbers. We followed the children until their 10th birthday at the latest which may have resulted in an underestimation of some of the co-morbidities as some diagnoses may occur later in life, for example, cancer diagnoses.

5 | CONCLUSION

In this population-based European study, we found a higher prevalence of children with congenital anomalies with the specified co-morbidities compared to reference children. This is important information for the clinicians taking care of these children, to aid in early diagnosis and counselling of parents whose children have been diagnosed with a congenital anomaly. Our results may also be used for strategies for prevention of these co-morbidities.

AUTHOR CONTRIBUTIONS

Mads Damkjaer: Conceptualization; methodology; validation; writing – review and editing; writing – original draft. **Stine Kjaer Urhoj:** Writing – review and editing; writing – original draft; methodology. **Joan Morris:** Conceptualization; methodology; validation. **Maria Loane:** Conceptualization; methodology; validation. **Elisa Ballardini:** Conceptualization; investigation; formal analysis. **Laia Barrachina-Bonet:** Conceptualization; investigation; formal analysis. **Clara Cavero-Carbonell:** Conceptualization; investigation; formal analysis. **Alessio Coi:** Investigation; formal analysis; conceptualization. **Mika Gissler:** Conceptualization; investigation; formal analysis. **Joanne Given:** Conceptualization; investigation; formal analysis. **Anna Heino:** Conceptualization; investigation; formal analysis. **Sue Jordan:** Conceptualization; investigation; formal analysis. **Amanda Neville:** Conceptualization; investigation; formal analysis. **Michele Santoro:** Conceptualization; investigation; formal analysis. **Joachim Tan:** Conceptualization; investigation; formal analysis. **David Tucker:** Conceptualization; investigation; formal analysis. **Diana Wellesley:** Conceptualization; investigation; formal analysis. **Ester Garne:** Conceptualization; methodology; validation; formal analysis; investigation.

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CONFLICT OF INTEREST STATEMENT

The authors have no conflicts of interest to declare.

ETHICS STATEMENT

This study was performed in line with the principles of the Declaration of Helsinki. All EUROCAT registries obtained ethical and other permissions for the data linkage according to their national legislations. University of Ulster obtained ethics permission for the Central Results Repository on 15 September 2017 (Institute of Nursing and Health Research Ethics Filter Committee, number FCNUR-17-000).

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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