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Manner of death, causes of death and autopsies in infants, children and adolescents

An overview from a German metropolis 2002–2012

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Abstract

Child mortality is an issue that is repeatedly discussed internationally and is subject to strong fluctuations depending on the country and region and the respective levels of development. Several studies on child mortality are available from e.g., the USA; however, data from institutes in Germany are still lacking.

The present study compared data on the manner and causes of deaths of infants, children and adolescents in Germany from 2002 to 2012 on different levels (the Institute of Legal Medicine and the Public Health Department, both in Cologne, as well as nationwide) with international data. Special attention is paid to autopsy figures and cases of sudden infant death syndrome (SIDS).

Throughout the observation period, child mortality decreased overall in all levels of data. Mortality rates were highest in the first year of life, with natural causes of death (premature birth, malformations, SIDS) dominating. With increasing age the number of non-natural deaths and thus, accident-related deaths, especially transportation accidents, increased.

Reasons for the reduced number of cases can be nationally effective prevention and awareness campaigns as well as constantly improving medical care. At a local level, targeted educational work leads to higher numbers of autopsies, particularly in cases of SIDS. In principle, the results of this study are generally comparable with other studies on child mortality, although the available data can only be used for detailed analyses to a limited extent

Keywords

Federal Statistical Office · SIDS · Autopsy rate · Public Health Department · Mortality

Introduction

The mortality rate of children and adolescents varies greatly from country to country and from one region to another [1–4]. Special attention is paid in worldwide research to the mortality of children under the age of 5 years [1–4]. The WHO has identified six major causes of child mortality: pneumonia (19%), diarrhea (18%), malaria (8%), neonatal pneumonia or sepsis (10%), preterm delivery (10%) and asphyxia at birth (8%) [1]. In 2008, infections (pneumonia, diarrhea and malaria)

accounted for 68% of the worldwide mortality of children under 5 years old while 41% of children died in the neonatal period due to preterm birth complications, asphyxia, sepsis and pneumonia [2]; however, in countries with high, medium and moderate mortality of under 5-year-olds, pneumonia and preterm birth complications remained the main causes while in countries with low mortality rates congenital abnormalities remained the main cause [4]. Studies have shown that child and adolescent mortality generally appears to be decreasing, presumably because of the sig-



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Table 1 Manner of death and causes of death causing unnatural manner of death in different age groups based on autopsies performed in a local Institute of Legal Medicine

	Infants < 1 year	Children and adolescents 1– < 15 years	Adolescents 15–18 years
Number of case files, n (%)	147/267 (55)	98/267 (37)	22/267 (8)
Manner of death	147 (100)	98 (100)	22 (100)
Natural	84 (57)	17 (17)	4 (18)
Unnatural	10 (7)	55 (56)	15 (68)
Unexplained	53 (36)	26 (27)	3 (14)
Unnatural manner of death	10 (100)	55 (100)	15 (100)
Not classified	6 (60)	6 (11)	3 (20)
Accident	2 (20)	31 (56)	7 (47)
Homicide	2 (20)	14 (26)	1 (7)
Suicide	0	0	4 (26)
Iatrogenic	0	4 (7)	0

nificant increase in attention to the topic in recent years [4–6].

In the USA, a nation comparable to Germany in terms of industrialization and prosperity, infectious diseases have recently played only a minor role in child mortality [7]. That study also clearly emphasized that the causes of death differ depending on the age of the child or adolescent and that certain age groups also have different mortality rates. Child and adolescent mortality are also dominated by a large number of non-natural events (drowning, transport accidents, drug abuse) [7]. Several studies have focused on how to prevent these events and in particular on preventing suicide [8–15].

A syndrome of particular forensic relevance concerning deaths in infancy is the sudden infant death syndrome (SIDS). This is a subcategory of sudden unexpected death in infancy, a sleep-related death in infancy (< 12 months). The SIDS is characterized by a death without explainable reasons, even after a detailed investigation of the case, including clinical evaluation and autopsy [16–18].

The aim of this study is to provide an overview of the most frequent manners and causes of death of children and adolescents in a German city with over 1 million inhabitants (Cologne) in the years 2002–2012. Specifically, the focus is on forensic aspects of cases classified as non-natural death, on autopsies at the Institute of Legal Medicine and on comparability of regional and nationwide data concerning manners and causes of death.

Material and methods

Data acquisition

Institute of Legal Medicine

All autopsies of children and adolescents aged 0 to < 18 years performed in the years 2002–2012 in the Institute of Legal Medicine in Cologne were analyzed in terms of manner and causes of death. Cases concerning natural manner of death were subdivided into different causes of death, such as congenital organ malformation (subcategorized to heart, lung, brain and kidney malformation), malignancies (subcategorized to brain tumors, leukemia, soft tissue tumors), infections, premature births, neurological causes, chromosomal abnormality, prenatal and perinatal asphyxia. Cases concerning unnatural manners of death, such as accidents, suicides or homicide, were considered separately. The SIDS cases were categorized as a special subgroup.

Public Health Department

Subsequently, the death certificates for the deaths of all children and adolescents aged 0 to < 18 years in the years 2002–2012 were inspected at the local Public Health Department in Cologne and the respective manner and causes of death were reviewed. All key facts as well as all demographic and forensically relevant information was recorded and collected in detail using the statistical software IBM® SPSS® Statistics (IBM Corp. Released 2019. IBM SPSS Statistics for Windows, Version 26.0. Armonk, NY: IBM Corp). The manner and

causes of death were divided into the same categories as in the autopsy cases, also with special attention to SIDS cases. In those cases, additional public prosecutor's file numbers were noted on the death certificates. They were compared with the files of the Institute of Legal Medicine.

Federal Statistical Office

In addition, publicly accessible data from the Federal Statistical Office [19] on the deaths of children and adolescents in Germany from 2002–2012 were viewed and visualized. A limitation was evident here since the definition of the age groups (< 1, 1 to < 15, 15 to < 20 years) used by the Federal Statistical Office extends beyond the age of 18. The Federal Statistical Office provided a total of 80 different causes of death (regardless of the manner of death), which can be gathered from the homepage of the Federal Statistical Office (<https://www-genesis.destatis.de/genesis/online>) [19]. For better comparability, natural causes of death were grouped into the same categories as in the autopsy cases and the cases from the Public Health Department (except the ages of 19 and 20 years).

Statistical analysis

All statistical evaluations were performed using IBM® SPSS® Statistics (version 26). In detail, the basic statistical functions such as mean(x, ...), median(x, na.rm = FALSE, ...) were applied. Binomial {stats} functions were used to estimate the *p* values, e.g., `dbinom(x, size, prob, log = FALSE)`. Statistical significance was established from $p < 0.05$. Trends and trend lines were calculated using a best fit regression model by a (minimal) linear least square estimate as $\min \sum_i (y_i - \hat{y}_i)^2$ with trend lines t and $\hat{y}_i = t(x_i)$ for the set of given datapoints (x_i, y_i) in the considered 11 years.

Results

Institute of Legal Medicine

Manner of death

In the years 2002–2012 a total of 4971 autopsies and 276 autopsies of children (0–18 years; 5.6%) were conducted at the Institute of Legal Medicine. Only 267 cases

Table 2 Cases of suspected sudden infant death syndrome (SIDS) according to death certificates 2002–2012

	Suspected SIDS
Number of case files, n (%)	51 (100)
Age in months (mean; median; range)	3; 3; 0.3–11.3
Sex, n (%)	
Male	34/51 (67)
Female	17/51 (33)
Procedure in the Institute of Legal Medicine, n (%)	
Not registered	9/51 (18)
Registered as transit without external postmortem examination	6/51 (12)
External postmortem examination	3/51 (6)
Autopsy	33/51 (64)
Results of autopsy	33 (100)
Compatible with SIDS	25/33 (76)
Internal cause of death	5/33 (15)
Not finally clarified	2/33 (6)
Abusive head trauma	1/33 (3)

Table 3 Causes of death causing unnatural manners of death in different age groups based on death certificates accessible at local Public Health Department

	Infants < 1 year	Children and adolescents 1–< 15 years	Adolescents 15–18 years
Number of case files, n (%)	16/126 (13)	56/126 (44)	54/126 (43)
Unnatural manner of death	16 (100)	56 (100)	54 (100)
Not classified	3 (19)	0	3 (6)
Accident	4 (25)	42 (75)	35 (64)
Homicide	3 (19)	4 (7)	6 (11)
Suicide	0	2 (4)	7 (13)
Iatrogen	3 (19)	8 (14)	3 (6)
Premature birth	1 (6)	0	0
Abortion	2 (12)	0	0

could be included in the current evaluation due to incomplete datasets. **Table 1** shows the numbers of each manner of death separated by different age groups. To improve comparability, the age groups were taken from the age groups used by the Federal Statistical Office.

Causes of death causing an unnatural manner of death

Table 1 also shows numbers of variant causes of death causing an unnatural manner of death in different age groups. These figures were also inspired by age groups and categorization in data from the Federal Statistical Office. A more differentiated breakdown was not possible due to partly discarded files of the oldest cases, as only basic documentation could be investigated. To maintain uniformity, this

categorization was continued for all subsequent years.

Causes of death causing a natural manner of death

According to the data of the Institute of Legal Medicine ($n = 140$), the most frequent cause of death causing a natural manner of death in infants under 1 year old ($n = 110$) was SIDS ($n = 81$, 74%). Among children and adolescents between 1 and < 15 years old ($n = 26$), it was chromosomal/genetic/metabolic disorders ($n = 6$, 23%), unspecified infections and pneumonia/bronchitis ($n = 5$, 19% each). For adolescents older than 15 years, there were only 4 cases with a cause of death causing a natural manner of death with unspecified infections and pneumonia/bronchitis ($n = 2$ in total each; 50% each).

SIDS

In 33 of the autopsies, the death certificate contained a suspicion of SIDS. **Table 2** shows the cases with suspected SIDS according to the death certificates. It is noticeable here that statistically significantly fewer female infants died from SIDS ($p = 0.012$).

Public Health Department

Manner of death

According to the death certificates provided by the local Public Health Department, 1053 children and adolescents aged 0 to 18 years (male $n = 578$, 55%; female $n = 475$, 45%; mean age 3.12 years; median age 0.17 years, divided into infants < 1 year $n = 703$, 67%, children and adolescents 1–< 15 years $n = 242$, 23%, adolescents 15–20 years $n = 108$, 10%) died in Cologne between 2002 and 2012. The division of age groups presented here is also related to the data of the Federal Statistical Office, for better comparability. The majority of deaths were in the group aged under 1 year ($n = 703$, 67%). The distribution of different manners of death can be seen in **Fig. 1**.

Causes of death causing an unnatural manner of death

A special focus was set on the causes of death causing an unnatural manner of death, differentiating between the age groups (**Table 3**). Due to the low number of cases ($n = 126$, 12% of 1053 cases in total), the cases were summarized over the years.

Causes of death causing a natural manner of death

According to the data of the Public Health Department, the most frequent causes of death causing a natural manner of death for infants under 1 year of age were premature birth ($n = 312$, 46%), heart malformations ($n = 117$, 17%) and chromosomal/genetic/metabolic disorders ($n = 64$, 10%). The most frequent causes of death causing a natural manner of death among children and adolescents between 1 and 15 years of age were brain tumors ($n = 33$, 19%), chromosomal/genetic/metabolic disorders ($n = 26$, 15%) and heart malformations ($n = 23$, 13%).

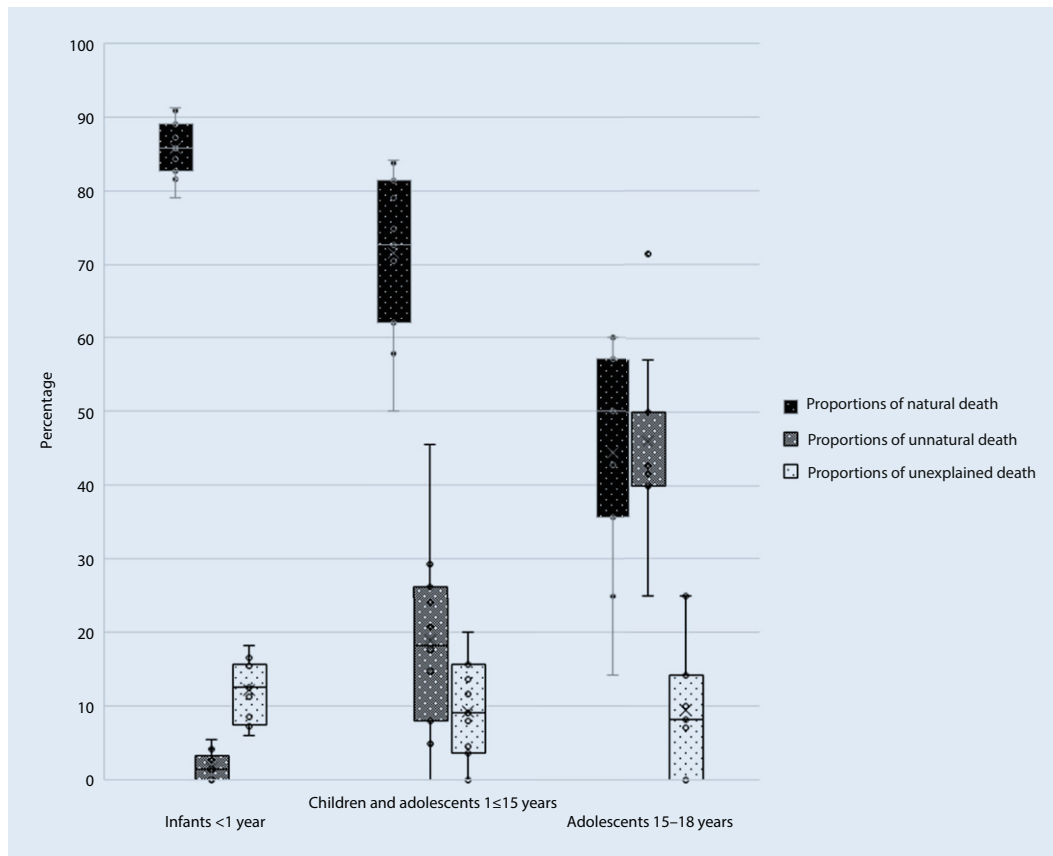


Fig. 1 ◀ Distribution of each manner of death in different age groups based on death certificates accessible at the local Public Health Department

Among young people older than 15 years, the most frequent causes of death causing a natural manner of death were chromosomal/genetic/metabolic disorders ($n=11$, 23%) and leukemia, connective tissue tumors and neurological disorders ($n=5$, 10% each).

Federal Statistical Office

Manner of death

According to the data from the Federal Statistical Office concerning manners of death in different age groups, in total 59,156 children and adolescents aged 0 to 20 years died in Germany between 2002 and 2012 (male $n=35,429$ (60%), female $n=23,735$ (49%); infants <1 year $n=28,555$ (48%), children and adolescents 1–<15 years $n=14,916$ (25%), adolescents 15–20 years $n=15,693$ (27%); mean or median age cannot be deduced from the available data). The majority of deaths were in the age group under 1 year ($n=28,555$, 48%). Distributions of different manners of death can be seen in **Fig. 2**.

Causes of death causing an unnatural manner of death

For this data set, again, a special focus was set on the causes of death causing an unnatural manner of death in each age group. For infants <1 year ($n=645$), unspecified accidents ($n=282$, 43%) and homicides ($n=232$, 35%) dominate the causes of unnatural death. For children and adolescents 1–<15 years ($n=3810$), accidents involving means of transport ($n=1519$, 40%), unspecified accidents ($n=689$, 18%) and accidents involving drowning and sinking ($n=525$, 13%) were major causes of unnatural deaths. In the age group of adolescents >15 years ($n=9397$), accidents involving means of transportation ($n=5996$, 64%) and suicides ($n=2338$, 25%) clearly dominate the unnatural causes of death. Additionally, trends regarding causes of death causing an unnatural manner of death could be derived from data of the Federal Statistical Office. Those trends show falling numbers of causes of death causing unnatural manners of death. This fall is particularly evident in the figures for accidents in-

volving means of transport (reduction in the number of cases between 12.9% and 18.7% per year), caused by falls (reduction in the number of cases between 5.1% and 11.5% per year) and accidental exposure to smoke, fire and flame (reduction in the number of cases between 14.9% and 22.9% per year).

Causes of death causing a natural manner of death

According to the data of the Federal Statistical Office, the most frequent causes of death causing natural manners of death for infants under 1 year are certain states with origins in the perinatal period ($n=14,074$, 49%), unspecified malformations ($n=7564$, 27%), additionally heart malformations ($n=2085$, 7%) and SIDS ($n=2697$, 9%). The most frequent causes of death causing natural manners of death among children and adolescents between 1 and <15 years of age are unspecified malignomas ($n=2759$, 28%), unspecified malformations ($n=1879$, 19%) and neurological reasons ($n=1567$, 16%). Among adolescents between 15–20 years,

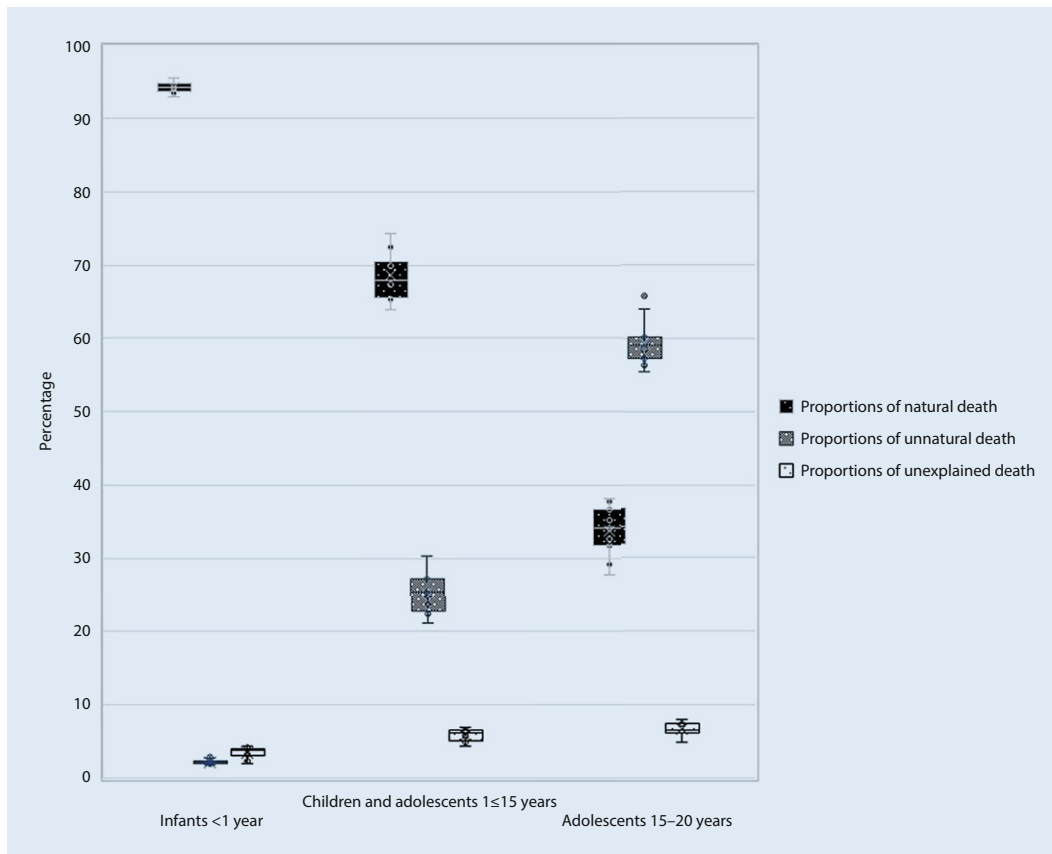


Fig. 2 ◀ Distribution of each manner of death in different age groups based on data of the Federal Statistical Office

the most frequent causes of death causing natural manners of death are unspecified malignomas ($n = 1503$, 34%), additionally lymphomas ($n = 499$, 11%), neurological reasons ($n = 865$, 20%) and unspecified malformations ($n = 465$, 10%).

SIDS

Special emphasis was also set on the cases of SIDS, whereby here also cases of children older than 1 year are registered in the data of the Federal Statistical Office (◼ Fig. 3). For a statistical and trend analysis, only deaths < 1 year, according to the definition of sudden infant death [16], were considered. 2697 infants died through SIDS from 2002 to 2012 (male $n = 1640$, 61%; female $n = 1057$, 39%). Here, as for the data from the Institute of Legal Medicine in the same period, significantly fewer female infants were affected ($p < 0.01$). The trend analysis for these data shows a decreasing death rate in general. For male infants, the decrease of average annual death rate over the observation period was 12.85% and for female infants 16.25%.

Basic epidemiological data

In addition, the basic epidemiological data on population figures, birth and death rates in Germany and, in particular, in Cologne were analyzed. Compared to Germany, Cologne saw its population and birth rate rising over the years under consideration; however, the number of inhabitants younger than 18 years declined for both areas. The death rates of those under 20 years of age vary for Germany as a whole between 0.8% and 0.5% of the total death rates, with a decreasing tendency, and the figures of those under 18 years of age for Cologne between 1.5% and 0.8%, also with a decreasing tendency.

Discussion

Using data from a German local Public Health Department, this retrospective study evaluated manners and causes of death in infants, children and adolescents and compared collected data to cases of a German Institute of Legal Medicine and data for the whole of Germany, accessible

at the Federal Statistical Office. To the best of our knowledge, studies with a comparable research approach, in particular, the possibility of comparing manners and causes of death at different levels (local Institute of Legal Medicine, local Public Health Department and throughout Germany) are not known; however, such a comparison is important to clarify to what extent the data are comparable or differ, depending on which data are used, and that it may already be useful to make detailed analyses at the local level, especially with regard to preventive measures. In the literature, the main focus is on prevention of early childhood mortality and suicides [1–15].

It is only reasonable to analyze the manners of death and causes of death at the level of a Public Health Department and at the federal level with the help of death certificates, which in turn are specific to each country. It is, however, generally known and also scientifically well investigated that the data to be collected in this way are sometimes of inferior quality, partly because forms are often incor-

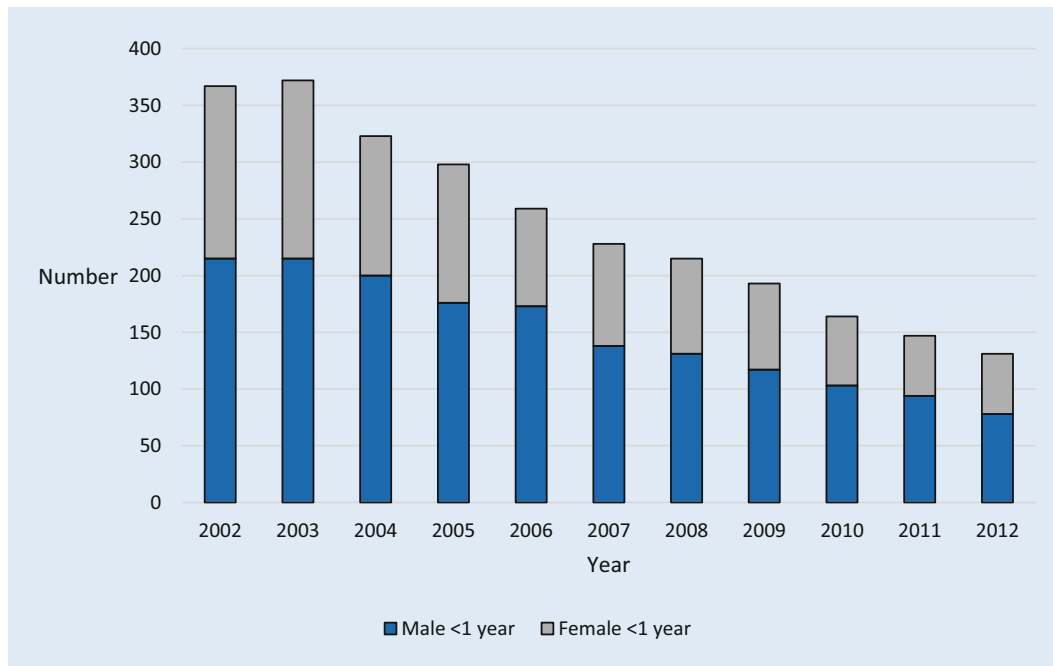


Fig. 3 ◀ Cases of suspected SIDS (sudden infant death syndrome) in Germany (in data of Federal Statistical Office cases of children > 1 year were also categorized as SIDS)

rectly completed. In addition, the causes of death are only verified by autopsies to a small extent and are therefore prone to errors, as are the resulting statistics on causes of death [20–25]. This error tendency is illustrated in the data available for the present study through the example that cases of SIDS contain children older than 1 year, which is wrong by definition [16]. A basic comparison of available autopsy cases with the causes of death on the death certificate and a correction of these could be an opportunity to improve the quality of the available data.

Another limitation of this study is the comparability of the different data from different sources. When comparing retrospectively collected data from different sources, it follows that these data were not collected a priori for optimal comparability, which, e.g., results in data not fitting in the age groups based on data from the Federal Statistical Office. In addition, the evaluation of data from the Federal Statistical Office showed little detail (e.g., age grading, subcategories of malignomas or infections) in its documentation, particularly with regard to natural causes of death.

However, analyzed data, with all its flaws, pitfalls, and shortcomings, provide the only way to compare across multiple levels (regional and national). For better

comparability, prospective data collection would be necessary; however, this hardly seems possible on a larger scale due to the fundamentals of data collection and protection.

In general, our study reveals decreasing rates of deaths in infancy, childhood and adolescence, particularly in Cologne in contrast to the background of (additionally) rising birth rates, regardless of manners and causes of death. Highest rates of death were observed in the smallest age group of infants < 1 year in all stages of data with mainly causes of death causing a natural manner of death, e.g., preterm birth, intrauterine causes, fatal malformations. These results confirm the findings on child mortality published by Liu et al., Byass et al. and the ones reported by the UN for countries with generally low child mortality [4–7]. Additionally, in the age group of the 1–15-year-olds, causes of death causing natural manners of death dominated at all levels of data acquisition except for the cases of the Institute of Legal Medicine. These, however, are biased by the fact that the commissioning courts and public prosecutors' offices primarily instruct an autopsy on cases of non-natural or unexplained manners of death. On the other hand, the data show that not every case of unnatural manner of death is autopsied at this age. As a result, it can be

assumed that numerous homicides may remain undetected [26, 27].

Causes of death causing unnatural manners of deaths increase at all levels of data collection with the age of the children and adolescents. Here, accidents generally predominate, especially accidents involving means of transport and accidents involving drowning and sinking. Among the over 15-year-olds, the growing importance of suicides should also be emphasized. Despite the increasing number of causes of death causing unnatural manners of death with age, however, there was a general decrease in the number of deaths over the observation period. Particularly noteworthy is the very marked decrease in accidents involving means of transport in all age groups. These declines can certainly be explained by a variety of measures and campaigns. There has not only been an increase in vehicle safety over the years, and still is today, and growing attention is being paid to road safety [28]. Just as importantly, improved medical care, especially intensive care measures, have certainly contributed to reducing not only accident-related deaths but also causes of death causing natural manners of death. In principle, prevention methods seem to be effective (for example concerning suicide prevention [8–15]).

When looking at the special cases of SIDS, it was noticeable in a Germany-wide comparison that the number of deaths dropped, with SIDS being one of the three most frequent causes of death causing a natural manner of death in infancy nationwide during the observation period. Information campaigns [29], starting in the early 1990s, seem to have brought a lasting reduction in mortality here and should be maintained or even intensified as numbers remain high. As described in the literature [30], statistically significantly fewer female infants died from SIDS in material of the Institute of Legal Medicine and data of the Federal Statistical Office. According to the death certificates, the autopsy rate in Cologne (64% of SIDS cases) is higher than the national average of about 50% [31], which is most likely due to the responsible public prosecutor's focus on clarification. In 76% of the cases, this suspected diagnosis could finally be confirmed by an autopsy in Cologne. Only one case, primarily categorized as SIDS, turned out to be an abusive head trauma (AHT).

Conclusion

In summary, due to heterogeneity and lack of detail, the available data are only suitable to a limited extent for a comparison on different levels. In this context, the possibility of standardized prospective data collection would be desirable for further analyses as well as the possibility of correcting causes of death on the death certificate after autopsy has been performed.

The comparison of the available data at different levels shows a general decrease in the number of deaths of infants, children and adolescents, as can be seen worldwide. This decline can be attributed to a variety of preventive measures (road traffic, water, smoke alarm, SIDS, suicides), as well as to generally improving medical care. Nevertheless, causes of death causing natural manners of deaths in younger infants and children (e.g. premature birth, malformations and SIDS) play a major role, in contrast to the causes of death causing an unnatural manner of death that dominate for older children and adolescents, especially those caused by accidents. The available data therefore reflect a distribution of causes of death corresponding to a western country with generally low infant mortality.

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Declarations

Conflict of interest. K. Feld, D. Feld, K. Quandt and S. Banaschak declare that they have no competing interests.

Ethical standards. For this article no studies with human participants or animals were performed by any of the authors. All studies performed were in accordance with the ethical standards indicated in each case.

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Todesart, Todesursachen und Obduktionen bei Säuglingen, Kindern und Jugendlichen. Ein Überblick aus einer deutschen Großstadt 2002–2012

Kindersterblichkeit ist ein Thema, das international immer wieder diskutiert wird und je nach Land und Region sowie dem jeweiligen Entwicklungsstand starken Schwankungen unterliegt. Es liegen mehrere Studien zur Kindersterblichkeit z. B. aus den USA vor. Daten von Instituten in Deutschland fehlen jedoch noch.

Die vorliegende Studie vergleicht Daten zu Todesarten und Todesursachen von Säuglingen, Kindern und Jugendlichen in Deutschland von 2002 bis 2012 auf verschiedenen Ebenen (Institut für Rechtsmedizin und Gesundheitsamt, beide in Köln, sowie bundesweit) mit internationalen Daten. Besonderes Augenmerk wird auf die Obduktionszahlen und Fälle von plötzlichem Kindstod (SIDS) gelegt.

Während des gesamten Beobachtungszeitraums ist die Kindersterblichkeit auf allen Datenebenen insgesamt zurückgegangen. Die Sterblichkeitsraten waren im ersten Lebensjahr am höchsten, wobei natürliche Todesursachen (Frühgeburt, Missbildungen, SIDS) dominierten. Mit zunehmendem Alter stieg die Zahl der nicht natürlichen Todesfälle und damit auch die Zahl der Unfälle mit Todesfolge, insbesondere der Verkehrsunfälle.

Gründe für den Rückgang der Fallzahlen können national wirksame Präventions- und Aufklärungskampagnen sowie eine sich ständig verbessernde medizinische Versorgung sein. Auf lokaler Ebene führt eine gezielte Aufklärungsarbeit zu höheren Obduktionszahlen, insbesondere bei SIDS. Die Ergebnisse dieser Studie sind grundsätzlich mit anderen Studien zur Kindersterblichkeit vergleichbar, wenngleich die vorliegenden Daten nur bedingt für detaillierte Analysen genutzt werden können

Schlüsselwörter

Statistisches Bundesamt · SIDS · Obduktionsrate · Gesundheitsamt · Sterblichkeit