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The epidemiology of funnel chest repairs in Germany: monitoring the success of Nuss' procedure

Andreas Heydweiller¹ and Christina Oetzmann von Sochaczewski^{1,2*}

Abstract

Background: In recent years, the Nuss procedure was gaining ground in pectus excavatum repair, but the scientific focus had been on complications compared to conventional repairs. Despite a substantial prevalence of pectus excavatum in population-based studies, the adoption of minimally invasive funnel chest repair and subsequent replacement of conventional procedures has not been assessed on a population-based level.

Methods: We analysed German administrative case-based data on funnel chest repairs separate by age group and operative procedure: conventional or minimally invasive. Changes over time between 2010 and 2018 were analysed by linear regression.

Results: There were $\bar{x} = 256$ operations per year, which did not change throughout the study time, but following the introduction of minimally invasive repairs, their usage increased particularly in males aged 15 to 19 years by 8.7 procedures per year ($P = 0.0142$) and was accompanied by a concomitant decrease in conventional repairs in all relevant age groups. We observed a shift of operations towards the age group of 15 to 19 years, whose numbers increased by 5.3 yearly procedures ($P = 0.0222$), whereas they decreased in all other relevant age groups. These shifts could not be observed in females in a similar fashion, but in both males and females, the numbers of minimally invasive per conventional repair increased.

Conclusions: In Germany, the introduction of the Nuss procedure did result in a concentration of funnel chest repairs in adolescence and a replacement of conventional repairs. Data from other healthcare systems are missing but are direly needed to assess the current situation in other healthcare systems.

Level of evidence: III.

Keywords: Pectus excavatum, Minimally invasive repair, Health services research, Age groups, Epidemiology

Background

Much has been written about the “right” procedure for the repair of pectus excavatum since the introduction of the Nuss procedure [1]. The main focus had been its complication rate in the analysis of the National Surgical Quality Improvement Program for both children [2]

and adults [3], also in comparison with Ravitch repair [4]. Although a considerable prevalence of pectus excavatum has been reported in population-based analyses [5, 6], similar data on the epidemiology of funnel chest repair is missing, particularly in adults. We aimed to address this issue by analysing the national hospital statistics of Germany with respect to pectus excavatum repairs in all age groups.

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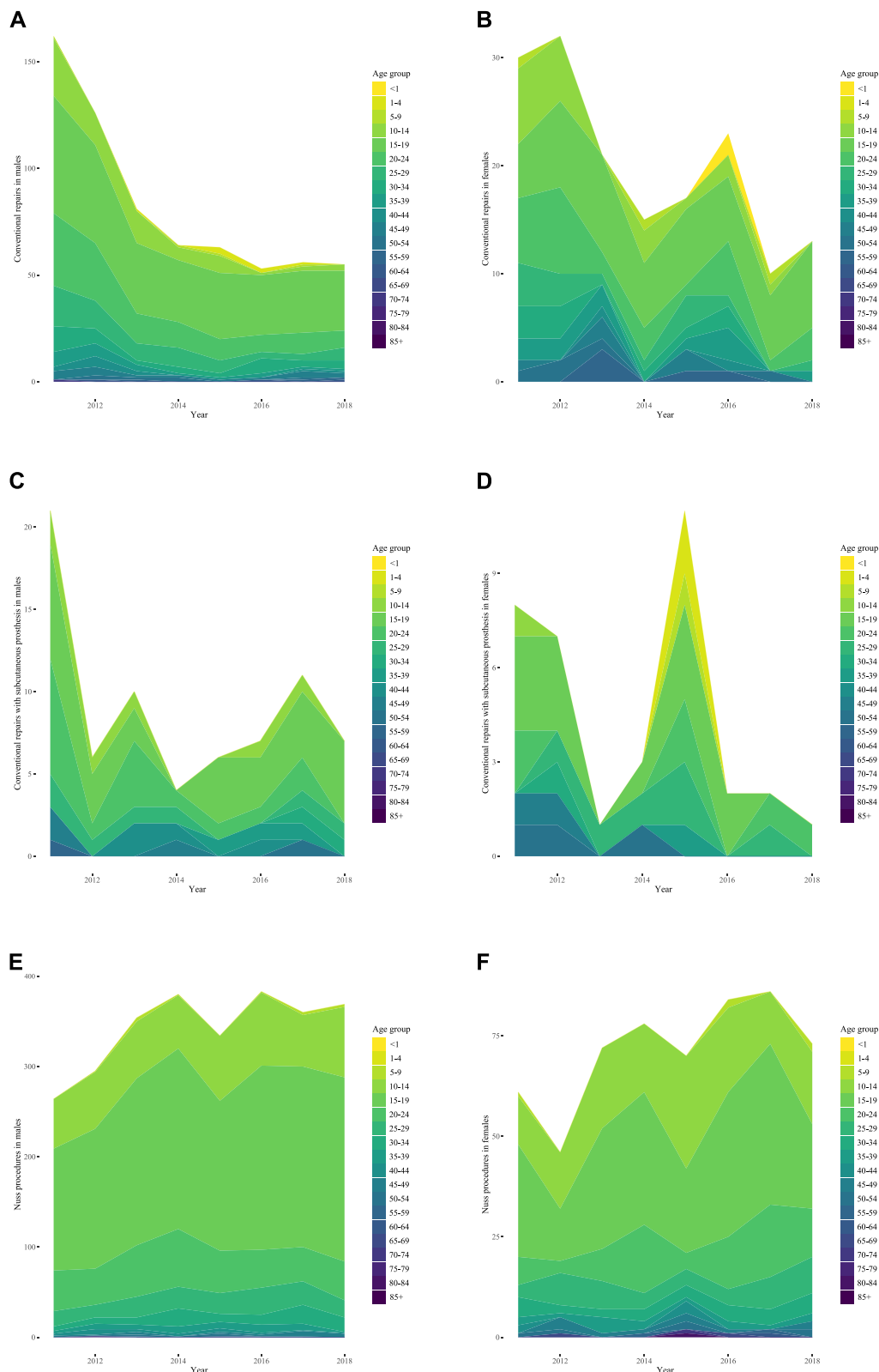


Fig. 1 Number of funnel chest repairs in the German population separated by sex and age. **A** Conventional repairs in males. **B** Conventional repairs in females. **C** Conventional repairs with implantation of a subcutaneous implant in males. **D** Conventional repairs with implantation of a subcutaneous implant in females. **E** Nuss procedures in males. **F** Nuss procedures in females

Methods

We obtained aggregated datasets from the *Statistisches Bundesamt* (Federal Statistics Office) including procedures of the German Modification of the International Classification of Diseases – version 10 for the years 2010 to 2018. The starting year was enforced by the data, because the Nuss procedure was not separately assessed before. We included all codes relevant for the repair of pectus excavatum: conventional repairs (OPS 5-346.a0), implantation of a subcutaneous prosthesis (OPS 5-346.a1), and Nuss procedures (OPS 5-346.a6). Population-based rates of repair were calculated by division of surgical procedures by the official population number on the reporting day of the *Statistisches Bundesamt* and provided in cases per 100,000 people. This was done separately for the age groups provided within the data. Detailed properties and pitfalls of these data have been discussed elsewhere [7]. The administrative database is derived from hospital reimbursement statistics and covers cases, but not individual patients. Studies using administrative data are exempt from ethical approval, because the case-based data cannot be traced back to the individual patient [8].

Statistical analyses were conducted using R (RRID: SCR_001905) (version 3.5.3) with its generic stats4 package [9], if not stated otherwise. Changes over time were analysed by ordinary least squares linear regression [10–13], whose requirements of normality of residuals were checked by using the Kolmogorov-Smirnov test and the presence of homoscedasticity was verified by the Breusch-Pagan test, both from the *olsrr* package (version 0.5.3) [14], aided by visual analysis of QQ plots [15].

Results

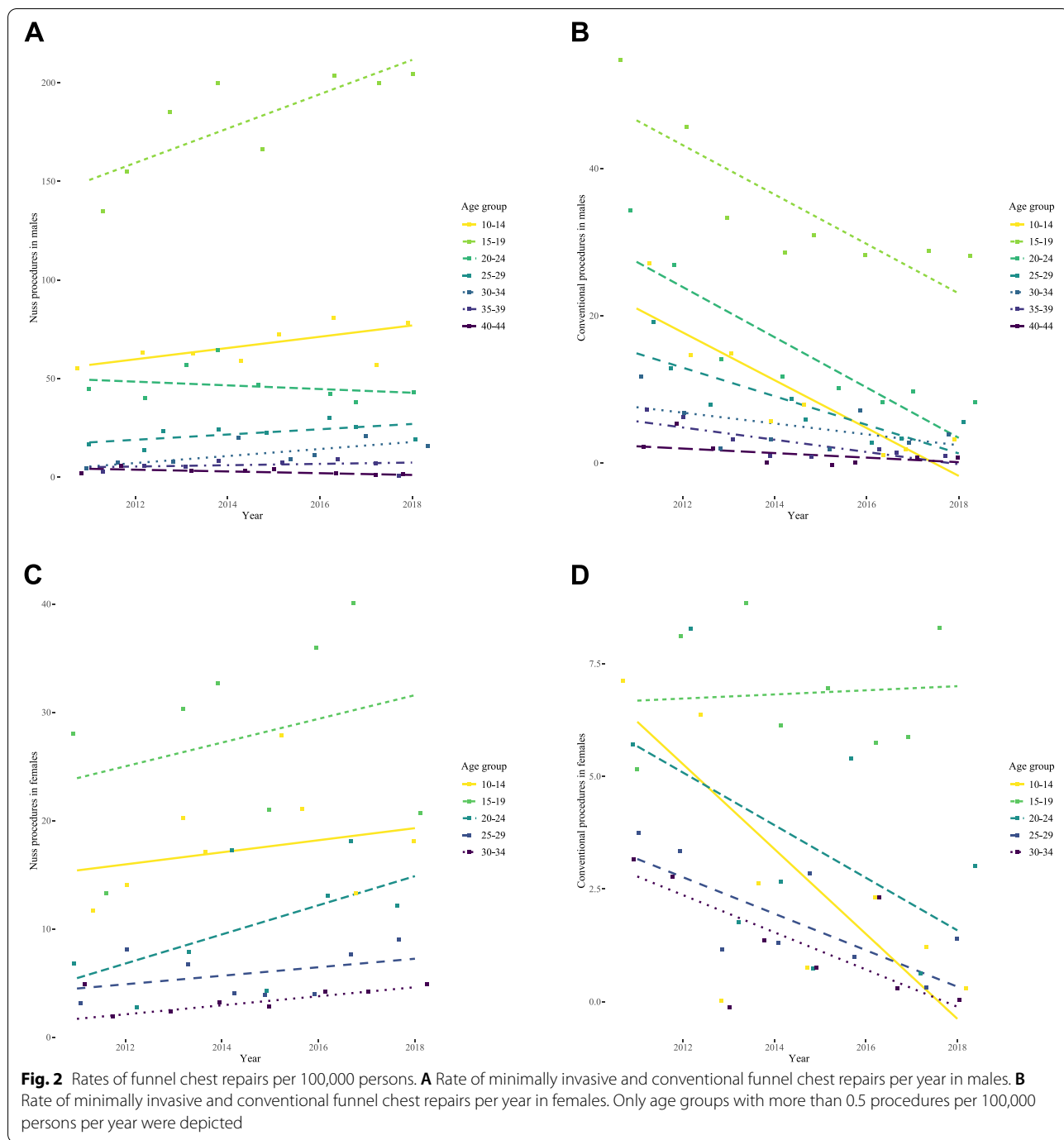
Since 2011, the number of conventional funnel chest repairs declined sharply in both males (Fig. 1A, C) and females (Fig. 1B, D), whereas the number of Nuss repairs rose in a similar fashion (Fig. 1F, G). In general, the operations of funnel chest repair with implantation of a subcutaneous prosthesis were rare in patients of both sexes (Fig. 1C, D). The total number of procedures did not change over time, but with an increasing fraction of minimally invasive procedures, the number of males operated on between 15 and 19 years of age rose by 5.3 procedures ($F(1,6) = 9.364, P = 0.0222$) per year in total. This was however just a shift towards an earlier operation during life, because the procedures in males between 20 and 24 years of age declined in a concomitant fashion by 5.1 yearly procedures ($F(1,6) = 23.33, P = 0.0029$).

Similar changes could not be observed in other age groups in both males and females. On a population-based level, this development did only alter the number of funnel chest repairs per 100,000 males aged 20 to 24

with -0.2 (95% confidence interval -0.3 to -0.09) per year ($F(1,6) = 20.42, P = 0.004$) and for those in the age group between 25 and 29 years with -0.06 (95% confidence interval -0.11 to -0.02) yearly procedures ($F(1,6) = 11.47, P = 0.0147$), whereas there were no changes in other age groups in males or in females at all (Fig. 2).

Among males in the age groups of 15 to 19 years, the number of Nuss' procedures increased by 8.7 (95% confidence interval 2.5 to 14.9) per year ($F(1,6) = 11.69, P = 0.0142$) but did not change in the other age groups (Fig. 3A). This increase was accompanied by a concomitant decrease in conventional repairs in the age group between 10 and 14 years, in which the number of procedures decreased by 3.3 (95% confidence interval 4.9 to 1.7) per year ($F(1,6) = 24.59, P = 0.0026$) (Fig. 3B). Similar decreases could be found in those aged 15 to 19 years with 3.4 (95% confidence interval 5.7 to 1.1) yearly procedures ($F(1,6) = 13.34, P = 0.0107$), in those of age 20 to 24 with a similar decrease of 3.4 (95% confidence interval 5.4 to 1.4) procedures per year ($F(1,6) = 17.14, P = 0.0061$), and patients aged 25 to 29 years, in whom the number of conventional procedures decreased by 1.9 (95% confidence interval 3 to 0.8) per year ($F(1,6) = 16.91, P = 0.0063$) (Fig. 3B). For the remaining age groups in males, there were no differences in yearly procedures (Fig. 3B). In females, there has been no similar steep increase in the numbers of Nuss' procedures in all age groups (Fig. 3C), but the data would be more compatible with a slight increase in the age groups between 15 to 19 and 20 to 24, although there is too much variability between the individual data points to clearly support this impression. Decreasing numbers of conventional procedures in females aged 10 to 14 years with 0.8 (95% confidence interval 1.5 to 0.1) per year ($F(1,6) = 8.4, P = 0.0274$) yearly procedures and a decrease of 0.4 (95% confidence interval 0.8 to 0.008) conventional procedures in females aged 25 to 29 years ($F(1,6) = 6.237, P = 0.0467$) also provide additional evidence for the aforementioned notion.

The substantial increase in minimally invasive funnel chest repairs could also be visualised by the number of Nuss procedures per conventional repair: They increased by 4.2 (95% confidence interval 0.6 to 7.7) per year in 10 to 14-year-old males ($F(1,6) = 8.54, P = 0.0266$), by 0.5 (95% confidence interval 0.08 to 0.97) in those aged 15 to 19 years ($F(1,6) = 8.422, P = 0.0273$), and by 0.5 (95% confidence interval 0.09 to 0.9) in males aged 20 to 24 years ($F(1,6) = 9.155, P = 0.0232$) but did not change in the other age groups in males (Fig. 4A). In females, this was only the case for those aged 25 to 29 years with a yearly increase of 1 (95% confidence interval 0.3 to 1.8) Nuss procedure per conventional repair ($F(1,6) = 11.82, P = 0.0138$). The data for the other age groups were also

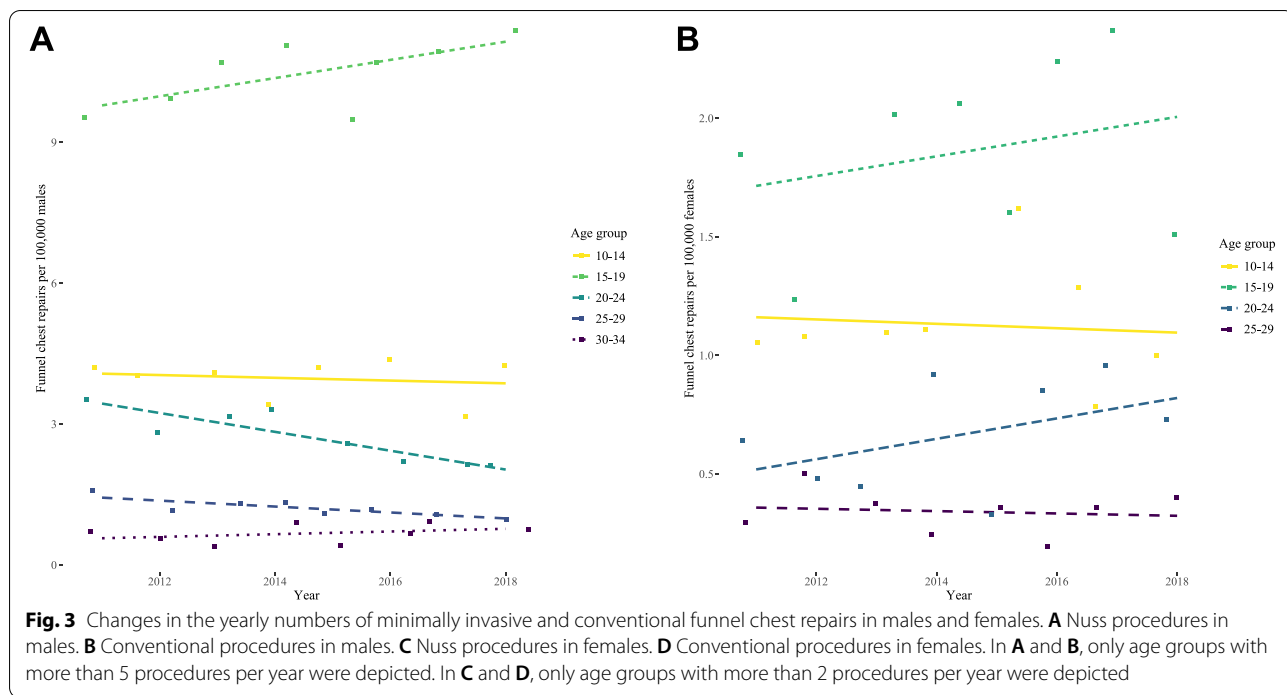


more compatible with an increasing relationship between minimally invasive and conventional funnel chest repairs but were too variable to model this increase by ordinary least square regression (Fig. 4B). This was heavily influenced by the small numbers of procedures in females (Fig. 1B, D, E), which made comparative modelling more difficult: For example, there were 18 Nuss procedures in 2018, but no conventional repair, which made

the calculation of a ratio mathematically impossible, but highlights the wide adoption of the Nuss repair, although it could not be modelled by linear regression.

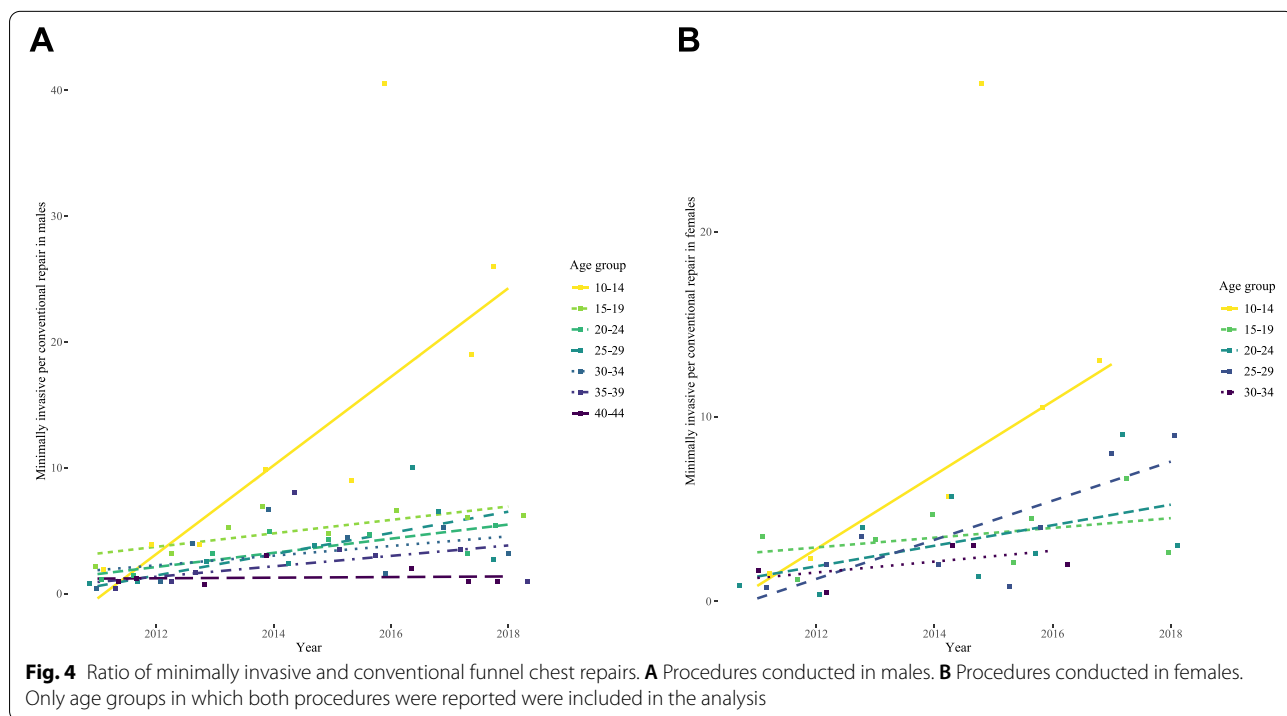
Discussion

Despite a considerable prevalence of pectus excavatum in population-based analyses [5, 6], similarly, also population-based data on the epidemiology of funnel chest



repair is missing. We aimed to fill this gap by analysis of the administrative, case-based German national hospital statistics, which has been described to be particularly useful to address such questions [15–17]. Using these data, we were able to describe a shift of procedures

towards minimally invasive repairs, particularly in males, with a concomitant decrease in conventional procedures, but without an increase in overall procedures. Contrary to other procedures that have been investigated using this dataset [11, 13], in the present analysis, we are able



to exclude that procedures have been missed due to their conduction on outpatients or even office-based, as this is impossible for funnel chest repairs.

Although the Nuss repair became much more frequent than conventional repairs in children aged 10 to 14 years, their numbers decreased and contributed towards the substantial increase in procedures in those aged 15 to 19 years. Although Nuss himself first developed his procedure in a 4-year-old boy [1], the median age at his centre has shifted from toddlers, as it was common with the open repair, to 14 years [18]. While its inventors claimed that the minimally invasive procedure might be conducted at any age [1], supported by some centres [19], many others described technical modifications to be frequently necessary for the minimally invasive operation to be successful in adults [20–22], including surgeons that operate on children and adolescents, too [23]. The marginal dissemination of such technical modifications might be a reason, why conventional repairs were still prevalent in Germany, particularly in adults aged 25 and older. On the other hand, techniques for open repair of pectus excavatum have enjoyed much popularity in Germany [24] and been advocated by influential surgeons of their periods such as Rehbein's method [25], the Willital-Hegemann procedure [26], and the Erlangen method [27]. We may thus not exclude that these factors played a role in the dissemination of the minimally invasive funnel chest repair.

Conclusions

We were able to demonstrate a shift towards minimally invasive repair of pectus excavatum in the last decade in Germany, although the total number of procedures did not change in the whole population. Nevertheless, population-based data on the epidemiology of funnel chest repair is missing and we hope to stimulate further research on this matter, particularly from other health-care systems.

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Authors' contributions

Conceptualisation of the study, data acquisition, analysis and interpretation, and writing: CO. Conceptualisation of the study, interpretation, and writing: AH. All authors have read and approved the final manuscript. All authors agree with the submission.

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Availability of data and materials

The data that support the findings of this study are available from the Statistisches Bundesamt (German federal statistics office), but restrictions apply to the availability of these data, which were used under license for the current study, and so are not publicly available. Data are however available from the

authors upon reasonable request and with permission from the Statistisches Bundesamt (German federal statistics office).

Declarations

Ethics approval and consent to participate

Strictly anonymous aggregated data such as the German national hospital statistics are exempt from ethical approval [8]. As such, no regulatory body may be able to grant ethical approval for something that is approved by the law itself. The owner of the data—the Statistisches Bundesamt (German federal statistics office)—licensed the data to the authors and did thereby authorise them to use and analyse the strictly anonymous data.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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