Østergaard *et al. BMC Medicine* (2025) 23:601
https://doi.org/10.1186/s12916-025-04414-2

BMC Medicine

RESEARCH

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Variations in surgical practice and adverse events following isolated proximal humerus fracture in adults – a comparative longitudinal cohort study of 53,852 patients from Denmark, England, and Sweden

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Abstract

Background Proximal humeral fractures (PHFs) are common injuries, but their management has remained controversial. Recent high-level evidence from randomized clinical trials has shown that for many PHFs, surgical treatment is not superior to non-surgical treatment. Our primary aim was to conduct a multi-nation assessment of temporal trends and changes in surgical treatment of isolated PHF in Denmark, England, and Sweden. A secondary aim was to estimate the incidence of serious adverse events (SAEs) within 30 days (and death within 90 days) of primary surgery.

Methods This population-based cohort study presents routinely collected data from Danish, English, and Swedish patient registries and electronic health records from 1998 to 2018. All adult patients with isolated PHFs combined with predefined surgical procedure codes were included. Age- and sex-specific incidence rates (IRs) of surgery and each surgical procedure per calendar year were calculated. Kaplan–Meier plots displayed patient survival for the study period. Incidence proportions of SAEs within 30 days (and death within 90 days) of surgery were computed.

Results A total of 54,077 primary surgical procedures, performed in 53,852 patients with isolated PHF, were included. Denmark and Sweden had the highest IR of surgery, with Denmark peaking at 17.4/100,000 person-years in 2011 and Sweden peaking at 18/100,000 person-years in 2013, while England peaked at 5/100,000 person-years in 2010. From 2004, plate fixation was the leading surgical procedure in Denmark and Sweden, while arthroplasty

The authors' contributions are listed on page 11.

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was the most frequent in England. The IR of surgery in Denmark and Sweden was 8–10 times higher for women aged 80 years than that observed in England. The 30-day incidence of SAEs varied between countries, ranging from 0.03% to 3.51%.

Conclusions Variations in surgical practice for isolated PHF exist between Denmark, England, and Sweden, with differences in overall IRs of surgery and preferred procedures. A complex interplay between hospitals, surgeons, healthcare systems, and evidence-based factors is likely to explain such variations. However, in all three countries, the IR of surgery, particularly for the use of locking plates, demonstrated a decline from 2013, coinciding with high-quality trials and meta-analyses suggesting that evidence-based factors are becoming more prominent in orthopaedic treatment decisions.

Keywords Shoulder fracture, Surgical treatment, Temporal trends, Incidence rates, Cohort study, Multi-national

Background

Proximal Humerus fractures (PHFs) are a common and potentially disabling injury [1]. Several studies have reported a higher mortality rate among older adults sustaining a PHF compared to the background population, as this type of fracture often serves as an indicator of frailty, which, in turn, increases the likelihood of experiencing serious adverse events (SAEs) [2, 3].

Surgical management has been considered an established treatment option in complex displaced PHFs [4, 5]. Over the past decades, implant choices have changed from Kirschner wires (K-wires) and screw fixation to plate fixation and humeral hemiarthroplasty, with a more recent transition towards reverse total shoulder arthroplasty. Besides the fracture morphology, the choice of intervention may depend on various factors, including the patient's overall health, functional demands, implant availability, healthcare system structure, marketing forces, and surgeons' preference [6].

The introduction of locking plates in the early 2000s offered the potential of achieving a stable anatomical reduction, leading to a significant increase in the number of surgeries performed for displaced PHFs [7, 8]. Since then, several randomized controlled trials (RCTs) have been conducted to compare surgical interventions with non-surgical treatment for displaced PHFs. In 2015, the results of the high-quality ProFHER trial were published and did not support the trend of increased surgery for patients with this fracture [9]. Furthermore, the authors of the Cochrane review and meta-analysis, initially conducted in 2015 and subsequently updated in 2022 with findings from 10 randomized controlled trials, concluded with high- or moderate-certainty that surgical intervention does not yield superior outcomes compared to non-surgical treatment at one and two years in older adults aged 60 years or older with displaced PHFs. They also stated that surgery may potentially increase the necessity for subsequent surgery [10, 11].

Real-world data offer a comprehensive mapping of events after trauma, including surgical interventions for PHF, temporal trends, as well as the incidence of SAEs [12–14]. They can be used to monitor surgical treatments, especially as high-level evidence often lags behind the implementation of new surgical techniques in clinical practice [15]. In addition, registry data offers an opportunity to detect variations in treatment methods between countries, which may provide useful insights for care pathway and treatment improvements for patients in these countries. While previous registry-based studies have described national-level trends in surgical treatment of PHF [7, 8, 16], comparative data across healthcare systems remain limited. To our knowledge, no prior study has examined surgical trends following PHF using harmonized methods across multiple Northern European countries.

The primary aim of this study was to conduct a multination study to assess and compare the temporal trends and changes in surgical treatment of isolated PHF in Denmark, England, and Sweden. A secondary aim was to estimate the incidence of SAEs within 30 days (and mortality within 90 days) of primary surgery, and to determine the impact of age, sex, and Charlson Comorbidity Index (CCI) upon these SAEs. Lastly, we aimed to investigate patient survival rates up to 18 years after surgery.

Methods

Study design

This multi-national population-based cohort study presents routinely collected data from Danish, English, and Swedish patient registries and electronic health records that were linked to national statistics in each country.

Data sources

We extracted individual participant data from the Danish National Patient Registry (DNPR), Hospital Episode Statistics Admitted Patient Care database (HES APC) for

England, and from the Swedish National Patient Register (SNPR) [12–14]. For simplicity, the term registry will be used in the following for all three countries.

The DNPR includes data from all Danish hospitals, both public and private, covering inpatient care and, since 1995, also including outpatient care. It captures information such as diagnoses, surgical procedures, treatments, complications, and hospital admissions. The DNPR also records information on outpatient visits to specialist clinics and emergency department visits [12]. After identifying the Danish study population in the DNPR, it was linked to the Civil Registration System (CRS) by the unique 10-digit personal identification number given to all Danes at birth or immigration since 1968. This allows individual-level linkage of data between multiple registries. The CRS also contains information on date of birth, age, sex, and vital status [17].

HES APC is a dataset containing data on all remunerated activity within National Health Service hospitals (NHS) or NHS-funded care in England where the patient requires an inpatient stay in secondary care. This includes day-case procedures and provides data on primary and secondary clinical diagnoses. Data can be linked at a patient level to all other secondary care episodes within the NHS, in addition to national mortality data [14].

The SNPR contains information from inpatient care and, since 2001, also from outpatient care, thus including hospital admissions, emergency department visits, and specialist outpatient visits. It covers data from all Swedish hospitals, both public and private, and includes information on patient demographics, diagnoses, treatments, and procedures [13]. To ensure a high degree of completeness from the SNPR, the Swedish data extract did not include data from before 2001.

Information about the specific content of each national patient registry is provided in Table S1 (Additional file 1: Table S1) [12–14, 17–21]. Furthermore, population data for incidence calculation were extracted from national statistics in each country [18, 20, 21]. All individual-level data were provided in a de-identified format.

Participants

Based on the International Classification of Diseases, 10th Revision (ICD-10), all adults (≥ 18 years) with PHF (S.42.2*) were identified in the three national patient datasets [11–13].

The participants' first fracture on each arm was included. In cases where laterality codes were missing, only the first fracture in one arm was included. Each index episode was analysed as an independent observation.

The exclusion criteria included the presence of bilateral PHF, any concurrent injury, and cancer registered at the same episode/index date as the fracture. This was to exclude polytrauma and pathological fractures. Specific details of the ICD-10 codes used for including and excluding patients, as well as recording comorbidities and SAEs, are found in Table S2 (Additional file 1: Table S2-S4).

Primary outcome

The primary outcome variables were the numbers of predefined surgical procedures for PHF. The Nordic Medico-Statistical Committee (NOMESCO) Classification codes (NCSP-codes) were used to identify surgical procedures linked to the ICD-10 code in Denmark and Sweden, while Operational Procedure Codes, 4th Edition (OPCS-4) were used to identify surgical procedures linked to the ICD-10 code in England [19, 22]. The predefined surgical procedures were: plate fixation, screw fixation, K-wire fixation, intramedullary nail (IM nail) fixation, external fixation, and arthroplasty. If patients had surgery within 30 days after the fracture index date, surgery was considered as initial treatment. If the index date of the surgical procedure was later than 30 days after the fracture, the initial treatment was categorised as non-operative, thus, they were excluded from the analysis. A complete coding list for the surgical procedures can be found in Table S2 (Additional file 1: Table S2). If more than one surgical procedure was performed on the same date and no data were available to classify which was the primary, the procedure was classified using a predefined hierarchy (Additional file 1: Table S5).

Secondary outcomes

Each specific surgical procedure was linked to the first episode of each SAE in a set of SAEs, occurring within 30 days after the index date of the surgical procedure. The SAEs were identified based on ICD-10 codes and included: stroke, respiratory tract infection, myocardial infarction, pulmonary embolus, urinary tract infection, and acute renal failure. In addition, mortality within 30 and 90 days was counted.

Covariates

To identify potential confounding, age, sex, and comorbidities were compared between surgical subgroups and between countries. Information on history of ischaemic heart disease (IHD), diabetes mellitus (DM), and chronic obstructive pulmonary disease (COPD) was extracted. The overall level of comorbidity was calculated as the CCI using the algorithm by Quan et al. [23]. In Denmark and Sweden, a one-year lookback period was applied when extracting past medical history and CCI variables, whereas in England, no time limit was applied to the lookback period due to the limitation of no outpatient and emergency department information within the English dataset.

Data processing

The primary investigators, responsible for the data in each participating country, cleaned and processed their national data. Data management flow charts for each country can be found in supplementary material (Additional file 2: Fig. S1a,b,c). Patient-level analyses were performed securely according to locally agreed data management procedures. Do-files were developed and shared among the three countries to enable reproducible analytical pipelines in each centre.

Statistical analysis

National baseline characteristics of patients divided by surgical subtype after isolated PHF were presented to identify potential differences in population profiles and sources of bias.

For each country, incidence rates (IR) per 100,000 person-years with 95% confidence intervals (95% CI) were calculated for all surgically managed PHFs and for each surgical subtype. This was done by using national population estimates. In addition, age- and sex-specific IRs were calculated. The annual surgical IRs for all three countries were plotted against the date of a Cochrane systematic review and a large clinical trial, to determine if there was an impact of trial recruitment or publication of high-quality evidence [9, 10].

SAEs, occurring within 30 days of each surgical procedure, were presented as cumulative incidence proportions (hereafter referred to as incidence) with 95% CI, assuming a normal approximation to the Poisson distribution for random count data.

Survival analysis using a Kaplan–Meier method was undertaken to show survival over the first post-operative year, as well as for the entire study period. Patients were censored at the date of death or end of follow-up, whichever came first.

Multivariable logistic regression analysis was undertaken to determine the impact of age (in 20-year age bands), sex, and overall comorbidity (using CCI categorised as (0–1), (2–3), (4+)) upon the rise of SAEs within 30 days as well as 30-day, 90-day, and 1-year post-operative mortality.

Aggregated results from each country were compiled by the first author. The statistical package Stata (version 17, StataCorp, College Station, TX) was used for data cleaning, pre-processing, and statistical analyses.

The study was reported according to the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) statement [24].

Results

A total of 54,077 primary surgical procedures performed in 53,852 unique patients with isolated PHFs met the inclusion criteria. In Denmark and Sweden, the median age was 68 years, compared to 63 years in England (Table 1). Across all three countries, patients treated with arthroplasty were the oldest (73 years), while patients undergoing screw fixation were the youngest (54.5–56.5 years). Table 1 also provides proportions of patients with a history of IHD, DM, and COPD, and the total CCI score for each surgical subtype. Table S6 presents patient characteristics divided by sex (Additional file 1: Table S6).

Denmark and Sweden had the highest overall IRs of surgery, with Denmark reaching a peak in 2011 (17.4 per 100,000 person-years), while Sweden peaked in 2013 (18 per 100,000 person-years). In England, the IR of surgery was highest in 2010, with 5 per 100,000 person-years. All three countries experienced a decline in the overall IR of surgery from 2013 onwards. In 2016, the difference in IRs between the three countries was still pronounced, with Denmark and Sweden exhibiting 2.5 to 3 times higher IRs of surgery compared to England (Fig. 1a,b,c).

In Sweden and Denmark, the IRs of surgery were 8 to 10 times higher for females aged 80 years (55 to 70 per 100,000 person-years) compared to that observed in England (7 per 100,000 person-years). From the age of 50 years onward, the IR of surgery was consistently higher for females compared to males across all three countries (Additional file 2: Figure S2a,b,c).

Plate fixation was the most commonly used surgical procedure in Denmark and Sweden from 2004, experiencing a steady increase until it reached a peak around 2010 in Denmark with an IR of 10 per 100,000 person-years, and between 2011 and 2013 in Sweden, where the IR reached 8.5 per 100,000 person-years. From 2013 onwards, the use of plate fixation underwent a decline in both countries (Fig. 2a,c). In England, the IR of plate fixation increased slightly from 1 per 100,000 person-years in 2005 to 2.8 per 100,000 person-years in 2010–11, followed by a modest decrease. Arthroplasty remained the most commonly performed procedure in England throughout the study period, with an IR between 2 and 4 per 100,000 person-years (Fig. 2b). In Denmark and Sweden, the IRs of arthroplasty procedures ranged from 5 to 6 per 100,000 person-years in 2013, after which the use decreased in both countries (Sweden from 2014), reaching a similar IR in 2016 as observed in England (Fig. 2a,b,c).

Table 1 Baseline characteristics of patients divided by surgical subtype type for isolated proximal humerus fracture

	Total	Plate	Screw	IM-nail	Ex-fix	K-wire	Arthroplasty
No. of cases (% of surgical type)							
Denmark	N = 11,453	N = 5,447 (47.6%)	N = 412 (3.6%)	N = 459 (4.0%)	N = 18 (0.2%)	N = 1,076 (9.4%)	N = 4,041 (35.3%)
England	N = 25,733	N = 9,744 (37.9%)	N = 891 (3.5%)	N = 4,259 (16.6%)	N = 35 (0.1%)	N = 1,246 (4.8%)	N = 9,558 (37.1%)
Sweden	N = 16,891	N = 7,462 (44.2%)	N = 603 (3.6%)	N = 2,901 (17.2%)	N = 37 (0.2%)	N = 1,504 (8.9%)	N = 4,384 (26.0%)
Median age (IQR)							
Denmark	68.0 (58.0–77.0)	65.0 (55.0–73.0)	56.5 (45.0–67.0)	69.0 (58.0–79.0)	59.0 (47.0–83.0)	68.0 (55.5–79.0)	73.0 (65.0–80.0)
England	63.0 (51.8–73.3)	62.0 (51.8–71.2)	54.5 (42.0–66.6)	62.4 (49.9–74.1)	63.2 (40.3–75.7)	64.8 (52.7–76.4)	73.5 (65.1–79.5)
Sweden	68.0 (59.0–76.0)	64.0 (55.0–73.0)	55.0 (43.0–65.0)	70.0 (61.0–80.0)	66.0 (53.0–73.0)	67.0 (56.0–75.0)	73.0 (66.0–79.0)
No. of females(%)							
Denmark	8,474 (74.0%)	3,941 (72.4%)	235 (57.0%)	303 (66.0%)	12 (66.7%)	765 (71.1%)	3,218 (79.6%)
England	17,985 (69.9%)	6,691 (68.7%)	424 (47.6%)	2,687 (63.0%)	26 (74.3%)	850 (68.2%)	7,307 (76.4%)
Sweden	12,190 (72.2%)	5,267 (70.6%)	308 (51.1%)	2,041 (70.4%)	21 (56.8%)	1,032 (68.6%)	3,521 (80.3%)
Past Medical History							
No. with Ischaemic Heart Disease (%)							
Denmark*	226 (2.0%)	93 (1.7%)	< 7*	11 (2.4%)	< 7*	25 (2.3%)	91 (2.3%)
England[a]	1,903 (7.4%)	589 (6.0%)	28 (3.1%)	243 (5.7%)	< 7*	91 (7.3%)	950 (9.9%)
Sweden*	1,683 (10.0%)	600 (8.0%)	36 (6.0%)	370 (12.8%)	< 7*	141 (9.4%)	530 (12.1%)
No. with Chronic Obstructive Pulmonary Disease (%)							
Denmark*	222 (1.9%)	98 (1.8%)	< 7*	14 (3.1%)	< 7*	22 (2.0%)	83 (2.1%)
England[a]	835 (3.2%)	277 (2.8%)	12 (1.3%)	122 (2.9%)	< 7*	45 (3.6%)	377 (3.9%)
Sweden*	2,512 (14.9%)	1,040 (13.9%)	54 (9.0%)	490 (16.9%)	< 7*	211 (14.0%)	711 (16.2%)
No. with Diabetes Mellitus (%)							
Denmark*	359 (3.1%)	155 (2.8%)	< 7*	21 (4.6%)	< 7*	20 (1.9%)	157 (3.9%)
England[a]	2,355 (9.2%)	797 (8.2%)	49 (5.5%)	335 (7.9%)	< 7*	122 (9.8%)	1,051 (11.0%)
Sweden*	554 (3.3%)	204 (2.7%)	< 7*	129 (4.4%)	< 7*	37 (2.5%)	177 (4.0%)
Charlson Comorbidity Index score (%)							
Denmark (1 year lookback)							
0	10,426 (91.0%)	5,004 (91.9%)	394 (95.6%)	379 (82.6%)	17 (94.4%)	966 (89.8%)	3,666 (90.7%)
1	402 (3.5%)	175 (3.2%)	7 (1.7%)	21 (4.6%)	< 7*	45 (4.2%)	154 (3.8%)
2	453 (4.0%)	196 (3.6%)	11 (2.7%)	35 (7.6%)	< 7*	47 (4.4%)	163 (4.0%)
3	71 (0.6%)	29 (0.5%)	< 7*	7 (1.5%)	< 7*	11 (1.0%)	24 (0.6%)
4	44 (0.4%)	20 (0.4%)	< 7*	< 7*	< 7*	< 7*	16 (0.4%)
5 +	57 (0.5%)	23 (0.4%)	< 7*	13 (2.8%)	< 7*	< 7*	18 (0.4%)
England (no time restriction in lookback)							
0	18,995 (73.8%)	7,380 (75.7%)	754 (84.6%)	3,306 (77.6%)	26 (74.3%)	953 (76.5%)	6,579 (68.8%)
1	5,302 (20.6%)	1,947 (20.0%)	113 (12.7%)	750 (17.6%)	7 (20.0%)	228 (18.3%)	2,257 (23.6%)
2	990 (3.8%)	309 (3.2%)	19 (2.1%)	143 (3.4%)	< 7*	41 (3.3%)	477 (5.0%)
3	294 (1.1%)	61 (0.6%)	< 7*	40 (0.9%)	< 7*	13 (1.0%)	175 (1.8%)
4	105 (0.4%)	33 (0.3%)	< 7*	14 (0.3%)	< 7*	< 7*	52 (0.5%)
5 +	47 (0.2%)	14 (0.1%)	< 7*	9 (0.2%)	< 7*	< 7*	18 (0.2%)
Sweden (1 year lookback)							
0	8,666 (51.3%)	4,283 (57.4%)	438 (72.6%)	1,276 (44.0%)	20 (54.1%)	787 (52.3%)	1,862 (42.5%)
1	1,678 (9.9%)	748 (10.0%)	46 (7.6%)	288 (9.9%)	3 (8.1%)	135 (9.0%)	458 (10.4%)
2	3,165 (18.7%)	1,192 (16.0%)	69 (11.4%)	605 (20.9%)	4 (10.8%)	299 (19.9%)	996 (22.7%)
3	1,338 (7.9%)	500 (6.7%)	19 (3.2%)	269 (9.3%)	5 (13.5%)	122 (8.1%)	423 (9.6%)
4	907 (5.4%)	320 (4.3%)	11 (1.8%)	199 (6.9%)	0 (0.0%)	82 (5.5%)	295 (6.7%)
5 +	1,137 (6.7%)	419 (5.6%)	20 (3.3%)	264 (9.1%)	5 (13.5%)	79 (5.3%)	350 (8.0%)

< 7* data minimized to prevent secondary disclosure of data, IM-nail = intramedullary nail; Ex-Fix = external fixation, K-wire = Kirschner wire, IQR = Interquartile range, *using a one-year lookback period, [a] no time restriction in look period applied

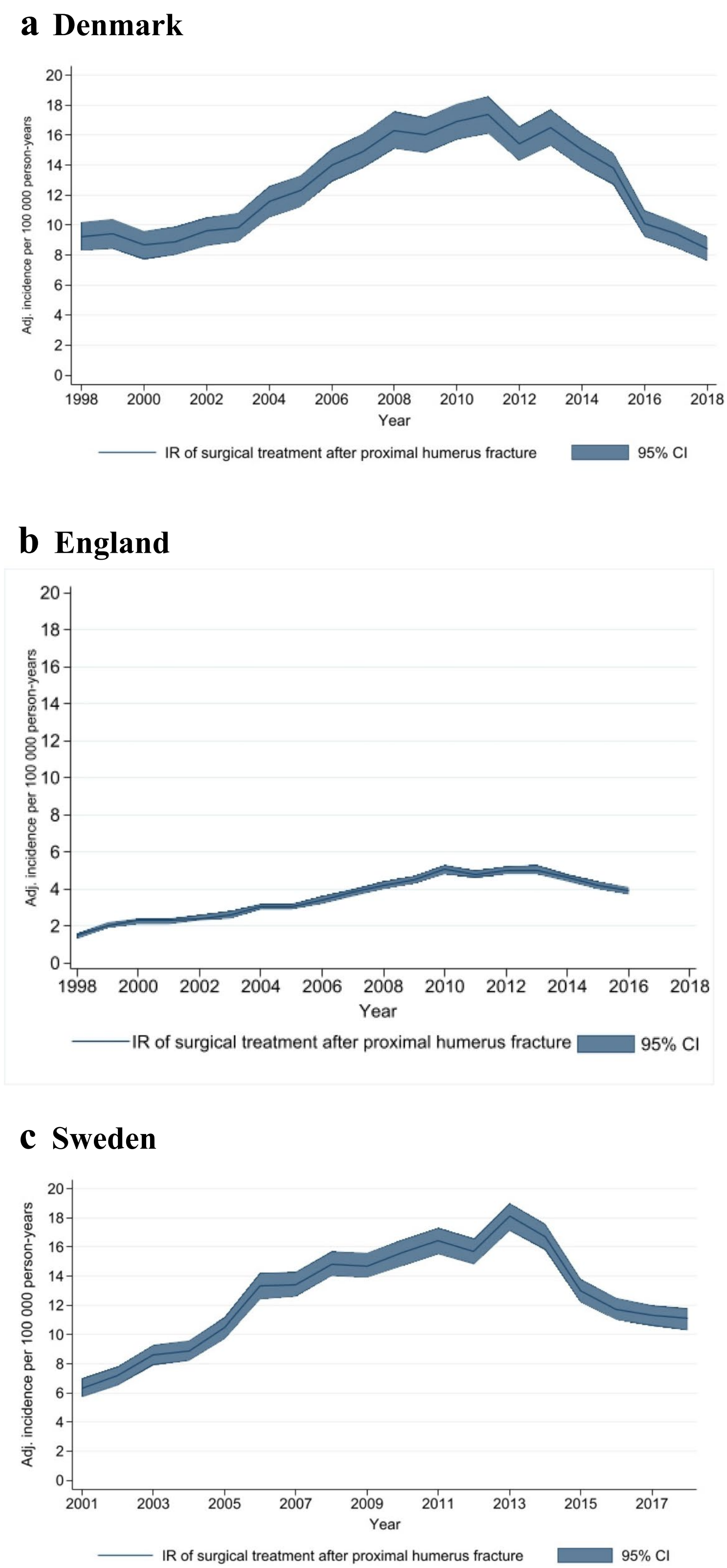

Fig. 1 **a**,**b**,**c** Incidence rate (IR) of surgery after isolated proximal humerus fracture over the total study period. Note: IR = incidence rate, 95% CI = 95% confidence interval

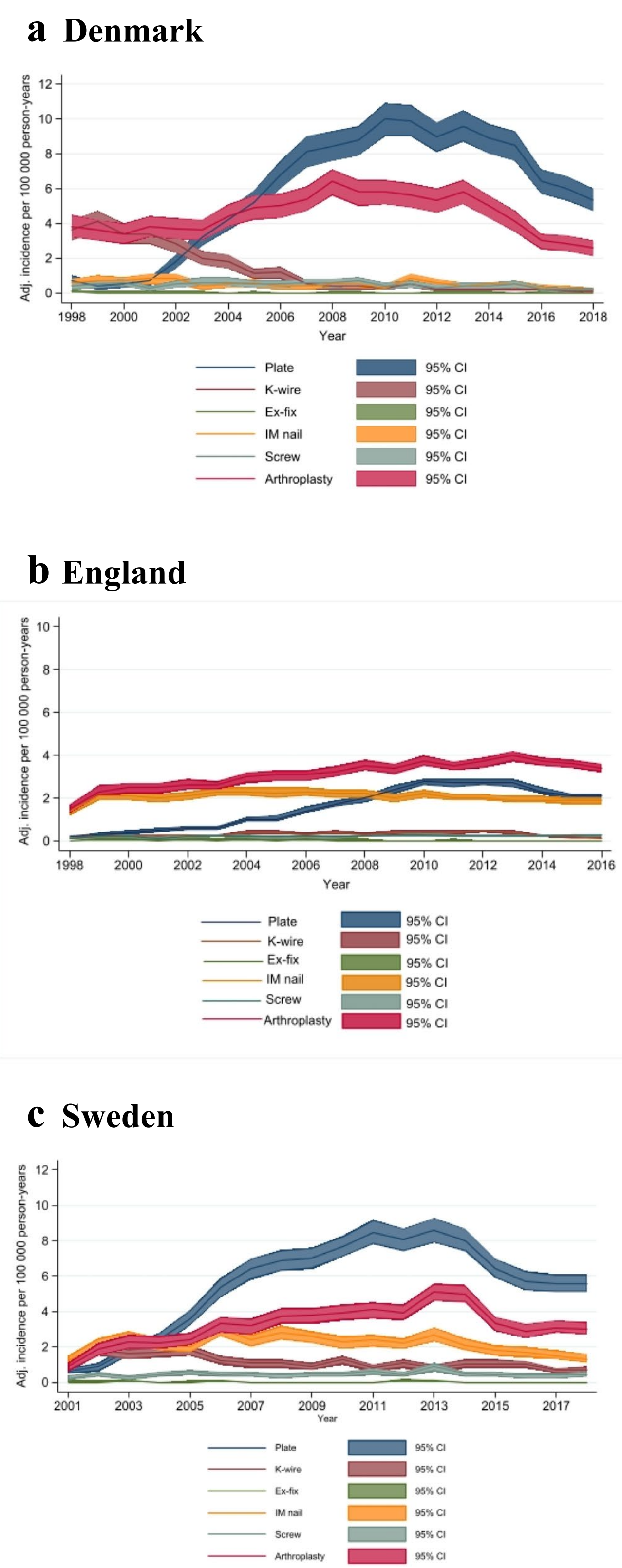

Fig. 2 **a**,**b**,**c** Incidence rates of surgical subtypes following isolated proximal humerus fracture. Note: IM nail = intramedullary nail, Ex-fix = external fixation, K-wire = Kirschner wire, 95% CI = 95% confidence interval

The total incidence of mortality within 30 and 90 days after surgery was higher in Denmark (1.21% and 2.65%) compared to those observed in England (0.67% and 1.36%) and Sweden (0.29% and 0.98%). Apart from mortality, Denmark and England had the lowest (total) incidence (0.03% to 1.26%) of the remaining predefined SAEs within 30 days compared to those observed in Sweden (0.62% to 3.51%) (Table 2).

Across the three countries, the survival rates for females after the first postoperative year ranged from 95% to 97.5%, and from 92% to 96% for males (Additional file 2: Fig. S3a,b,c). After 18 years, the survival rates had decreased to between 30% and 38% for females and between 35% and 48% for males (Additional file 2: Figure S4a,b,c). At both follow-up times, Denmark accounted for the lowest survival rate, while Sweden had the highest.

Multivariable regression analyses showed a consistent trend across all three countries: male gender, advanced age, and high CCI index score increased the risk of mortality within the first postoperative year, as well as the risk of suffering the predefined SAEs within 30 days of surgery. The specific odds ratio (OR) estimates are outlined in Table S7 and Table S8 (Additional file 1: Table S7-S8).

Discussion

PHFs are a common injury, and this study reveals large international variation in IRs of their surgical treatment between Denmark, England, and Sweden from 1998 to 2018. Sweden and Denmark had the highest IRs of surgery, with England showing the lowest. Notably, Denmark and Sweden showed a preference for utilizing locking plates, starting in 2004, following their introduction to the market. This trend was not observed in England, where arthroplasty remained the preferred surgical intervention throughout the study period. The IR of surgery in Denmark and Sweden was 8 to 10 times higher for women aged 80 years than that observed in England. Additionally, this study showed that the median age of patients undergoing surgical treatment for isolated PHFs in Denmark and Sweden was five years higher compared to their counterparts in England, suggesting differences in patient selection for surgery between countries. Sweden had the highest incidence proportions of SAEs within 30 days of surgery, except mortality, which was highest in Denmark within 30 and 90 days after surgery. Finally, there was variation in survival rates after surgery up to 18 years after surgery across all three countries.

It is noteworthy that across all three countries, the IRs of surgery, especially regarding the use of locking plates, declined from 2013. This decline coincided with the conduct of the ProFHER trial in England [9]. The trend continued after the publication of results and the Cochrane review in 2015 [10]. This shift in treatment trends observed in the three countries during the study period suggests that the findings, and possibly the mere initiation of large-scale studies, had an impact on treatment practices for patients with isolated PHF. While these studies cover the majority of PHF cases, they do not address younger patients or less common fracture types such as dislocated or head-split fractures. Finally, new models for implementation of evidence-based practice are currently being introduced by orthopaedic societies [25].

In a recent nation-based registry study, Brorson et al. investigated trends in the management of PHF from 1996 to 2018 in Denmark and reported temporal trends of surgery similar to those found in our study [7]. Sumrein et al. reported treatment trends in Sweden from 2001 to 2017, with findings that align with the surgical trends observed in our Swedish cohort [16]. These national registry studies offer important insights into within-country changes over time, however, they do not allow for direct cross-national comparison of surgical IR, subtype use, or SAE outcomes. In this study, we applied a harmonized methodological approach to enable comparison of surgical trends and serious adverse events (SAEs) following PHF across these national healthcare systems. Also in Germany, locking plates were the most commonly used implant between 2011 and 2016. However, unlike the trends observed in our study, Germany did not experience a decline in the use of locking plates during this period. Instead, they reported a 39% increase in surgery for PHF during the study period [15]. Thus, there is substantial variation in surgical trends, even among geographically proximate countries. Geographic variation in surgical treatment of PHFs has also been reported in other studies. Floyd et al. reported wide national variation in the surgery rates across the United States [26]. Lübbeke et al.'s multinational registry study found international variation in the use of shoulder arthroplasty, with higher IRs in Denmark and Sweden compared to the UK [27]. However, neither of the two studies investigated the variation in the use of different surgical subtypes across countries.

International variation in surgical trends most likely reflects several factors, such as differences in health care systems, capacity, and regulations across nations, including differences in the speed at which national orthopaedic communities will adopt new surgical methods [6]. In addition, marketing forces and surgeons' treatment preferences may also contribute to the variations in surgical trends [28].

Due to confounding by indication and differences in median age in the study populations across the three countries, we refrained from making conclusive statements regarding causality between the proportion of SAEs and the utilization of the different surgical

Table 2 Incidence of serious adverse events within 30 days (and 90 days for mortality) of surgery divided by surgical subtype for isolated proximal humerus fracture

	Total	Plate	Screw	IM-nail	Ex-fix	K-wire	Arthroplasty
Number (%) (95% CI of %)							
Mortality within 30 days							
Denmark	139 (1.21%) (1.02–1.43%)	45 (0.83%) (0.60–1.11%)	< 7*	20 (4.40%) (2.66–6.73%)	< 7*	22 (2.04%) (1.30–3.10%)	52 (1.30%) (0.10–1.70%)
England	173 (0.67%) (0.58–0.78%)	41 (0.42%) (0.30–0.57%)	< 7*	34 (0.80%) (0.55–1.11%)	< 7*	19 (1.52%) (0.92–2.38%)	77 (0.81%) (0.64–1.01%)
Sweden	50 (0.29%) (0.21–0.39%)	13 (0.2%) (0.09–0.30%)	< 7*	21 (0.72%) (0.44–1.10%)	< 7*	< 7*	10 (0.23%) (0.11–0.41%)
Mortality within 90 days							
Denmark	304 (2.65%) (2.36–2.97%)	97 (1.80%) (1.44–2.17%)	< 7*	42 (9.15%) (6.60–12.37%)	< 7*	43 (4.00%) (2.90–5.38%)	121 (3.01%) (2.49–3.60%)
England	352 (1.36%) (1.22–1.52%)	80 (0.82%) (0.65–1.02%)	< 7*	77 (1.80%) (1.43–2.25%)	< 7*	33 (2.65%) (1.82–3.72%)	155 (1.62%) (1.38–1.90%)
Sweden	165 (0.98%) (0.81–1.11%)	46 (0.62%) (0.45–0.82%)	< 7*	55 (1.90%) (1.42–2.46%)	< 7*	19 (1.26%) (0.76–1.97%)	40 (0.91%) (0.65–1.24%)
Stroke							
Denmark	46 (0.40%) (0.29–0.54%)	18 (0.33%) (0.20–0.52%)	< 7*	< 7*	< 7*	< 7*	18 (0.44%) (0.26–0.70%)
England	9 (0.03%) (0.02–0.07%)	< 7*	< 7*	< 7*	< 7*	< 7*	< 7*
Sweden	524 (3.10%) (2.28–3.37%)	177 (2.37%) (2.03–2.74%)	< 7*	135 (4.70%) (3.90–5.51%)	< 7*	44 (2.93%) (2.01–3.92%)	162 (3.70%) (3.14–4.31%)
Respiratory Tract Infection							
Denmark	145 (1.26%) (0.11–1.49%)	57 (1.1%) (0.79–1.41%)	< 7*	< 7*	< 7*	10 (0.93%) (0.45–1.71%)	68 (1.70%) (1.31–2.13%)
England	66 (0.26%) (0.20–0.33%)	21 (0.22%) 0.13–0.33	< 7*	< 7*	< 7*	8 (0.64%) (0.28–1.27%)	33 (0.34%) (0.24–0.48%)
Sweden	593 (3.51%) (3.23–3.80%)	226 (3.03%) (2.64–3.45%)	9 (1.50%) (0.68–2.83%)	127 (4.40%) (3.64–5.21%)	< 7*	45 (3.0%) (2.18–4.00%)	186 (4.24%) (3.65–4.89%)
Myocardial Infarction							
Denmark	31 (0.27%) (0.18–0.38%)	16 (0.29%) (0.17–0.48%)	< 7*	< 7*	< 7*	< 7*	13 (0.32%) (0.17–0.55%)
England	11 (0.04%) (0.02–0.08%)	< 7*	< 7*	< 7*	< 7*	< 7*	8 (0.08%) (0.04–0.16%)
Sweden	435 (2.60%) (2.34–2.83%)	150 (2.01%) (1.70–2.35%)	9 (1.50%) (0.68–2.83%)	85 (2.93%) (2.34–3.62%)	< 7*	33 (2.20%) (1.51–3.08%)	158 (3.60%) (3.06–4.11%)
Pulmonary Embolism							
Denmark	17 (0.15%) (0.09–0.24%)	< 7*	< 7*	< 7*	< 7*	< 7*	11 (0.27%) (0.14–0.49%)
England	12 (0.05%) (0.03–0.09%)	< 7*	< 7*	< 7*	< 7*	< 7*	10 (0.10%) (0.05–0.19%)
Sweden	173 (1.02%) (0.87–1.18%)	64 (0.86%) (0.66–1.09%)	< 7*	36 (1.24%) (0.44–1.10%)	< 7*	14 (0.93%) (0.51–1.56%)	57 (1.30%) (0.98–1.68%)
Urinary Tract Infection							
Denmark	93 (0.81%) (0.66–0.99%)	31 (0.60%) (0.39–0.81%)	< 7*	< 7*	7 (1.53%) (0.61–3.14%)	8 (0.74%) (0.32–1.46%)	46 (1.14%) (0.83–1.52%)
England	59 (0.23%) (0.17–0.30%)	17 (0.17%) (0.11–0.29%)	< 7*	< 7*	< 7*	< 7*	31 (0.32%) (0.22–0.46%)
Sweden	246 (1.46%) (1.28–1.65%)	107 (1.43%) (1.17–1.73%)	< 7*	40 (1.38%) (0.98–1.87%)	< 7*	17 (1.13%) (0.65–1.80%)	79 (1.80%) (1.42–2.24%)
Acute Renal Failure							
Denmark	12 (0.10%) (0.05–0.18%)	< 7*	< 7*	< 7*	< 7*	< 7*	7 (0.17%) (0.07–0.36%)
England	64 (0.26%) (0.19–0.32%)	18 (0.18%) (0.11–0.29%)	< 7*	< 7*	< 7*	< 7*	41 (0.43%) (0.31–0.58%)
Sweden	105 (0.62%) (0.51–0.75%)	41 (0.55%) (0.39–0.74%)	< 7*	27 (0.93%) (0.21–1.71%)	< 7*	< 7*	30 (0.68%) (0.46–0.97%)

< 7* data minimized to prevent secondary disclosure of data, IM-nail = intramedullary nail; Ex-Fix = external fixation, K-wire = Kirschner wire, 95% CI = 95% confidence interval

procedures. Our findings depict the incidences of SAEs among patients selected for surgical intervention, rather than indicating that SAEs were solely a result of surgery. Moreover, our analysis did not include non-surgically treated patients with PHF, which prevents an assessment of whether SAEs were directly attributable to the surgical intervention, although generally fitter people are more likely to receive surgery.

A notable strength of this study is the validity of the DNPR and the SNPR, which are known for their comprehensive coverage and high-quality data collection [12, 13, 29]. The HES APC is considered comprehensive in terms of coverage of the health system and detailed reporting of mortality events. However, research to validate the specific procedure codes used has yet to be published. Another strength of this study is its use of a large sample size comprising 54,077 surgical procedures conducted over a 20-year period in three northern European countries. To ensure comparability of results across countries, the three national study groups collaborated extensively on a study protocol for all stages of the study.

A limitation is that the content of the three patient registries, from which data were extracted, varied (Additional file 1:Table S1). Whereas the SNPR and DNPR include outpatient and emergency room visits, the HES APC strictly comprises data from patients who underwent hospital admission and does not include patients treated non-operatively who were not admitted to hospital. Nevertheless, HES APC does capture all patients who underwent surgery, including day-case surgery. To ensure comparability, we used national population estimates to calculate the IR of surgery. However, while we assume similar IR of PHF across the three countries, we cannot draw definitive conclusions about the exact disparity in surgical IRs between Denmark and Sweden versus England. While our analysis did not include non-surgically treated patients and thus cannot provide estimates of the total incidence of PHF, prior registry studies offer important context. Brorson et al. found that the incidence of PHF in Denmark remained stable between 1996 and 2018 [7], while Sumrein et al. reported a rise in incidence in Sweden between 2001 and 2008, followed by stabilization through 2012 [16]. These findings suggest that the observed decline in surgical incidence rates in our study is unlikely to be attributable to a general change in PHF incidence and is more likely explained by a shift in treatment practices. The English data include only inpatient episodes related to SAEs, while the Danish and Swedish data also capture outpatient episodes. Therefore, comparisons of SAEs across countries should be interpreted with caution, as should comparisons of CCI and past medical history. In all countries, the reported number of SAEs within 30 days may be underestimated. While conditions like stroke, pulmonary embolus, acute renal failure, and myocardial infarction, often lead to hospital admission, urinary tract infections and respiratory tract infections are sometimes treated in the community or by general practitioners.

In Denmark and England, the patient's first fracture on each arm was included and analysed as an independent observation. This decision was made to capture as many fractures as possible, assuming that a fracture on one arm does not influence the outcome of a fracture on the other arm. Since the SNPR lacks laterality, only the patient's first fracture in one arm is included. Therefore, it is likely that the total number of fractures in Sweden would have been higher if fractures in both arms had been included. Denmark and Sweden estimated past medical history and CCI using a one-year look-back period, while England did not impose any time restrictions. As a result, it is not possible to make a direct comparison of the patients' comorbidity profiles among the three countries.

Conclusions

This multi-national study has demonstrated that large variations in surgical practice exist between Denmark, England , and Sweden. These variations were observed in both the overall IR of surgery and in the preferred surgical procedures for isolated PHF. While it is likely that a complex interplay between hospitals, surgeons, and healthcare systems may explain some of these variations, high-quality orthopaedic evidence has traditionally been lacking. With the surgical community now delivering stronger evidence, and if patient outcomes are put first, such variations should diminish. However, in all three countries, the IR of surgery, particularly the use of locking plates, declined from 2013. This coincided with the publication of high-quality clinical trials and meta-analyses investigating the optimal treatment of these injuries. These changes in practice suggest that emerging evidence is becoming more prominent in trauma and orthopaedic surgery across the three countries.

Abbreviations

PHF	Proximal humerus fracture
IRs	Incidence rates
K-wires	Kirschner wires
RCTs	Randomized controlled trials
CCI	Charlson Comorbidity Index
DNPR	Danish National Patient Registry
HES APC	Hospital Episode Statistics Admitted Patient Care database
SNPR	Swedish National Patient Register
CRS	Civil Registration System
NHS	National Health Service hospitals
ICD-10	International Classification of Diseases, 10th revision
NOMESCO	Nordic Medico-Statistical Committee
NCSP-codes	NOMESCO Classification of Surgical codes
OPCS-4 codes	Operational Procedure Codes, 4th Edition
IM nail	Intramedullary nail
Ex-Fix	External fixation
IHD	Ischaemic heart disease

DM	Diabetes mellitus
COPD	Chronic obstructive pulmonary disease
95% CI	95% Confidence intervals
IQR	Interquartile range
STROBE	Strengthening the Reporting of Observational Studies in Epidemiology

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12916-025-04414-2.

Additional file 1: Table S1-S8. Table S1: Content of national registries used for data extraction in this study. Table S2: ICD-10 diagnosis and procedure codes utilized for data extraction. Table S3: ICD-10 diagnosis codes for serious adverse events. Table S4: ICD-10 codes for comorbidities in Charlson Comorbidity Index. Table S5: Predefined hierarchy for classifying surgical procedures when multiple procedures occur on the same date and primary procedure is unknown. Table S6: Patient demographics divided by sex for surgically treated isolated proximal humerus fracture. Table S7: Multivariable logistic regression model showing risk of mortality after surgical treatment of proximal humerus fracture, adjusted for age, sex, and CCI. Table S8: Multivariable logistic regression model showing risk of serious adverse events after surgical treatment of proximal humerus fracture, adjusted for age, sex, and CCI.

Additional file 2: Figure S1a,b,c-S4 a,b,c. Figure S1a,b,c: Data management flowchart for the Danish, English, and Swedish fracture cohort. Figure S2a,b,c: Age- and sex-specific incidence rates of surgically treated isolated proximal humerus fracture. Figure S3a,b,c: Survival rate within the first post-operative year after isolated proximal humerus fracture, divided by sex. Figure S4a,b,c: Survival rate during the total follow-up period after isolated proximal humerus fracture surgery, divided by sex.

Acknowledgements
We thank Martin Stisen for contributing to Danish data management.

Authors' contributions
HKØ, JCEL, RC, MT, DF, MC, SG, IM, APL, and JLR contributed to the study's conception and design. HKØ and MNM had full access to all Danish data, JCEL had full access to all English data, and ARQ and LFT had full access to all Swedish data. Danish data processing and analysis were conducted by MNM and HKØ, English data processing and analysis by JCEL, and Swedish data processing and analysis by ARQ and LFT. IM, APL, HEB, MT, and JLR provided valuable input during data processing to qualify meaningful and clinically relevant decisions. Data interpretation was performed by all authors. HKØ and APL drafted the original manuscript, and all authors provided critical review and shared final responsibility for the decision to submit the manuscript for publication. HKØ and MNM directly accessed and verified the underlying Danish data, JCEL and JLR directly accessed and verified the English data, and ARQ and LFT directly accessed and verified the Swedish data. All authors read and approved the final manuscript.

Funding
Funding was received from the regional agreement on medical training and clinical research (ALF, Region Stockholm) dnr. RS 2019–1054, Academy of Finland (APL) ref 341375, and Dagmar Marshall Foundation in Denmark. The English work was funded by Versus Arthritis (JCEL), Medical Research Council (JCEL), and we acknowledge the support of the National Institute for Health Research Barts Biomedical Research Centre (NIHR203330) (JCEL) and Royal College of Surgeons and National Joint Registry (RC). The funders of the study had no role in the study design, data collection, data analysis, data interpretation, or writing of the report.

Data availability
The datasets generated and analysed during this study are not publicly available. Access requires permission from the Danish Health Data Authority, Hospital Episode Statistics Admitted Patient Care database in England, and the National Board of Health and Welfare in Sweden.

Declarations

Ethics approval and consent to participate
Data access and approval were gained through national authorities. In Denmark, approval was gained by the Danish Data Protection Agency (reference no. 680317, case no. 1–16-02–100-20). In England, approval was gained by NHS Data Access Advisory group and NHS Digital data sharing agreement (DARS-NIC-29827-Q8Z7Q); the University of Oxford research services (Project ID 12787), and was registered at ClinicalTrials.gov (NCT03573765). In Sweden, approval was obtained from the regional ethics committee in Stockholm and the national ethical authority in Sweden (Dnr: 2013/581–31, 2020–04776, 2020/06182).

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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Received: 11 February 2025 Accepted: 30 September 2025
Published online: 03 November 2025

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