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ORIGINAL ARTICLE

Identifying proximal humerus fractures: an algorithmic approach using registers and radiological visit data

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Abstract

Summary In this study, we show that combining register and radiological visit data enables more accurate automated identification of proximal humerus fractures compared to traditional register analysis. In a cohort of 11,863 post-menopausal women, our proposed approach improved the coverage of identified fractures from 74 to 81%.

Purpose The aim of this study was to investigate how reliably proximal humerus fractures can be identified from different administrative datasets without manual review.

Method Using the national medical registers, namely the Care Register for Health Care and the Register for Primary Health Care Visits, as well as the regional radiological image archive PACS, we developed algorithms for automated identification of proximal humerus fractures. In addition to these sources, we used data from patient records as well as from the self-reports gathered by the Kuopio Osteoporosis Risk Factor and Prevention Study (OSTPRE) to establish a gold standard of fractures for validating the algorithms. This gold standard included proximal humerus fractures for a cohort of 11,863 post-menopausal women living in the Kuopio region between 2004 and 2022.

Results We report the national registers' yearly accuracy in identifying proximal humerus fractures. During the studied 19-year period, the registers' coverage initially improved but then settled at 75%. We show that the image archive provides almost complete coverage of radiographs for the fracture cases, but excluding false positives poses a challenge. In addition, we propose a simple approach that combines register and radiography visit data to improve the accuracy of automated fracture identification. Our algorithm improves the coverage from 74 to 81% and reduces the false discovery rate from 8 to 7% compared to the traditional register analysis.

Conclusion The proposed approach enables a more reliable way of identifying proximal humerus fractures from administrative data. This study contributes to the objective of automatically tracking all types of fragility fractures in large datasets.

Keywords Communication systems · Fragility fracture · Humerus · Image archive · Medical register · PACS · Picture archiving · Radiography · Radiological information system · RIS

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Introduction

Proximal humerus fractures rank among the four most prevalent types of fragility fractures in older people, along with hip, vertebral, and forearm fractures [1]. These four types are also called major osteoporotic fractures due to their strong association with osteoporosis and their significant impact on morbidity and mortality [2, 3]. Our prior study [4] demonstrated that identifying wrist fractures based on only register data poses limitations regarding fracture coverage and reliability. The reasons were connected to the fact that wrist fractures are predominantly treated in outpatient care. This is also the case with humerus fractures [5], raising the question of whether similar incompleteness in register data applies to them.

National registers serve as the standard data source for identifying diagnostic outcomes in epidemiological research. They offer structured data using standardized diagnostic codes such as the International Classification of Diseases (ICD) [6] and the International Classification of Primary Care (ICPC) [7]. The registers may appear comprehensive, but researchers should be aware of their data design and level of integration and the variability in treatment and reporting practices among care providers [8, 9]. Ignoring these issues can introduce bias in research results.

In Finland, the activities of health care providers are currently collected in two registers: The Care Register for Health Care (Hilmo) [10] and the Register for Primary Health Care Visits (Avohilmo) [11]. Hilmo replaced the previous Hospital Discharge Register in 1994. Since 1998, it has collected information on the activities of hospitals and other institutions providing inpatient care, as well as on hospital outpatient visits. Starting in 2011, Avohilmo expanded the registration to cover public primary care outpatient visits. The standard way of identifying a proximal humerus fracture from recent register data is by the ICD-10 code S42.2 representing a “fracture of upper end of humerus.” A suitable fracture-free clearance period is used to distinguish fresh fractures from readmissions, as the diagnosis is usually associated with several follow-up visits [12].

A potential approach to improve traditional register analysis is to complement it with information from the picture archiving and communication systems (PACS). Fragility fractures are diagnosed by conventional radiography, and PACS serves as a regional repository for radiological information, including X-ray images, radiological reports, and related metadata. If the healthcare organization uses a separate radiological information system (RIS) or collects the whole region’s radiological visit information in the hospital information system (HIS), these could also serve as sources of radiological visit data.

The classification of radiological exams used in Finland [13] is based on the Nordic Medico-Statistical Committee (NOMESCO) Classification of Surgical Procedures [14]. In case of a suspected proximal humerus fracture, a humerus X-ray (NB6AA/NB6BA/NB6DA) or shoulder X-ray (NB1AA/NB1BA/NB1DA) is performed, depending on the location of the symptoms. Follow-up radiographs are recommended 6 and 12 weeks after treatment [5, 12]. However, the same X-ray projections are also used to diagnose arthrosis, shoulder dislocation, and fractures of other bones in the same skeletal area. The radiographic findings are reported in a free-form text, which may also be missing in some cases. Therefore, advanced algorithms capable of analyzing textual reports, X-ray images, or radiography visit patterns would be required to identify proximal humerus fractures from radiological data automatically.

In many countries, registers provide relatively comprehensive hospital discharge data, and European validation studies on hip fractures have reported around 90% coverage [15, 16]. In contrast, few validation studies have focused on fracture types treated primarily in other than hospital settings [17]. In Finland, Koski et al. [16] reported a limited coverage of wrist fractures but did not observe the same limitation for proximal humerus fractures. In Germany, Koeppe et al. [18] found significant differences in proximal humerus fracture incidences calculated based on only inpatient data compared to including outpatient data. To date, the accuracy of identifying proximal humerus fractures based on recent Finnish register data is yet to be validated. Moreover, algorithmic methods to combine data from the registers and the radiological image archive have not been proposed in this context.

This study first aimed to gather a gold standard of proximal humerus fractures for the OSTPRE cohort using registers, self-reports, radiology reports, and patient records. Then, we sought to validate the diagnosis code reporting for these fractures in the registers. Finally, inspired by the approach proposed in our study on wrist fractures, our objective was to find algorithmic methods to enhance automated proximal humerus fracture identification by utilizing radiological visit data.

Material and methods

Gold standard

The participants in this study are a subcohort of the Kuopio Osteoporosis Risk Factor and Prevention Study (OSTPRE) [19]. Initiated in 1989, the OSTPRE study originally consisted of 14,220 post-menopausal women residing in the Kuopio Province, Finland. We had access to the patients’ register, health, and imaging records, and the cohort has been followed from the beginning by postal inquiries every 5th year. In these inquiries, the participants report, among other things, any suffered fractures, which are then checked from patient records to avoid false positives. The previously validated self-reports were one source of fracture information, but we also conducted a comprehensive search for all evidence on proximal humerus fractures from the national medical registers Hilmo and Avohilmo and the radiological image archive PACS to establish a gold standard of fractures (Fig. 1).

The procedure of establishing the gold standard followed the same principles as our previous work on wrist fractures [4]. From PACS data, we read all the radiological reports of the humerus and shoulder X-ray examinations conducted on the participants during the study period. The radiographs with missing or unclear reports were retrospectively reviewed by our radiologist. From the registers, we searched through the study period for contacts with ICD-10 diagnosis code S42.2. The found contacts were further investigated by checking other diagnosis and procedure codes dating near the fracture diagnosis and by cross-validating with self-reports, radiology reports, and patient records. When reasonable evidence of a proximal humerus fracture was found, the event was included in the gold standard. Other fracture types in the same area, such as glenoid fracture, acromion fracture, Hill-Sachs lesion, and Bankart lesion, were not included, as they are not considered major osteoporotic fractures.

At the time of this study, the PACS systems in Finland were regional. However, in recent years, healthcare organizations have been obligated to send radiological data to the National Patient Data Repository [20]. The coverage of this repository will continue to increase in the coming years. To simulate the future scenario and ensure a more meaningful comparison of data sources, we focused on the cohort participants who lived in the North Savo PACS coverage area during the study period. For clarification, the cohort of this study corresponds to the one referred to as the North Savo subcohort in our wrist fracture study. Nevertheless, we also report the results for the whole cohort in the supplementary material (Table SI1). The current North Savo PACS system started operating in 2003, so we defined our study period as beginning in 2004 and ending in 2022.

Algorithms

We developed fracture identification algorithms for different scenarios regarding available data sources and research purposes. When identifying fractures for large datasets

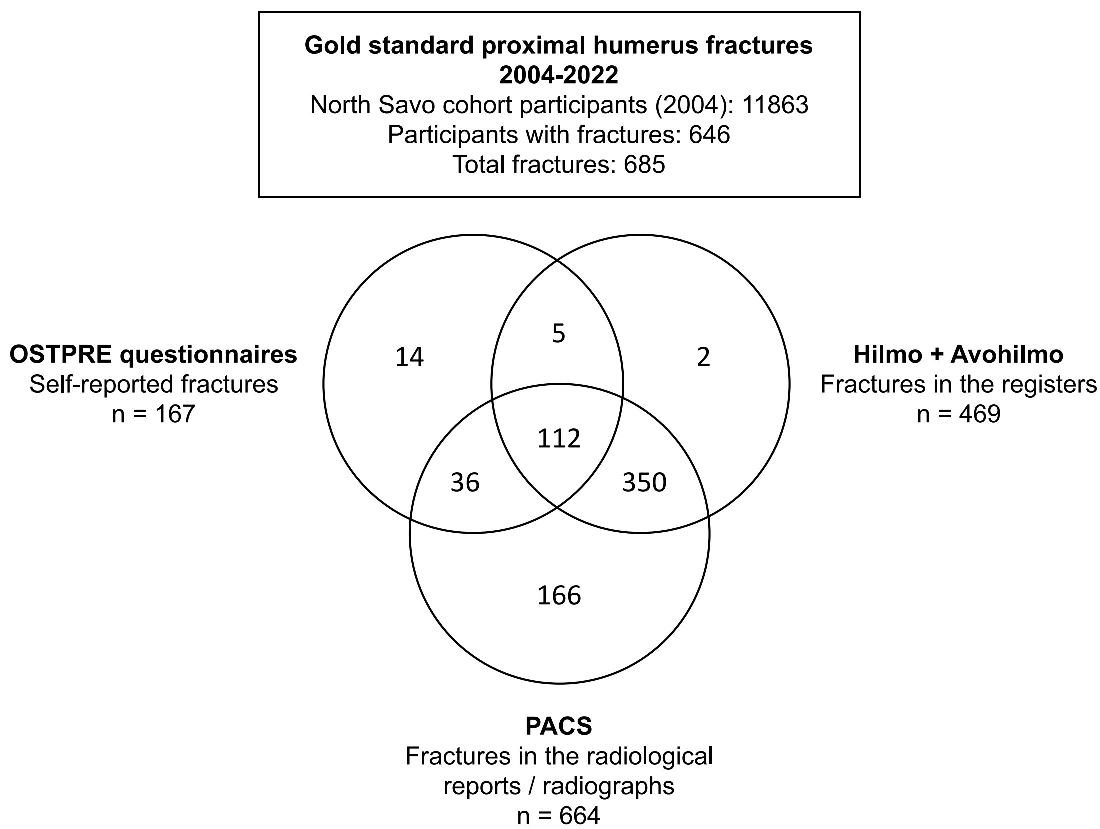

Fig. 1 The Venn diagram illustrating the number of gold-standard proximal humerus fractures found in the data sources. PACS provided considerable coverage, as only 21 fracture cases identified from other sources were missing from the image archive

automatically, a researcher may prioritize sensitivity or specificity depending on the research question. For instance, specificity is more important when picking fractures for case studies. On the other hand, if verifying identified cases from radiological reports is feasible, sensitivity becomes paramount as the false positives can be excluded manually.

Our traditional register analysis algorithm combines data from the Hilmo and Avohilmo registers and seeks S42.2 diagnosis codes with a clearance period of 365 days to identify incident fracture events. The analysis of clearance periods in the supplementary material (Fig. SI1) shows that a shorter clearance period would increase the false discovery rate while providing only marginal improvements in the coverage. The PACS algorithms, in turn, search for patterns of radiography visits within a 100-day window, in which routine follow-ups should usually take place [12], and thus employ a shorter clearance period. PACS 2+ and PACS 3+ algorithms identify fractures based on two or more and three or more emergency radiography visits, respectively. Finally, we formed combination algorithms that integrate the data from the registers and the image archive. Registers&PACS algorithm A considers only the S42.2 register events with one or more corresponding radiography visits in PACS. Registers&PACS algorithm B extends algorithm A by including additional diagnosis codes S42 (ICD-10, fracture of shoulder and upper arm), S423 (ICD-10, fracture of shaft of humerus), and L76 (ICPC2, other fracture) when they occur with two or more radiography visits. These less specific codes are sometimes used, for example, if the exact location of the fracture is unclear or if the fracture extends over several locations. The implementation of the algorithms is provided as open-source code (https://github.com/UEF-BBC/nissinen-fracture-identification-2024).

Results

The study encompassed a population of 11,863 participants from the beginning of 2004 to the end of 2022, during which the number of alive participants decreased to 6778, and the average age increased from 67 to 85 years. For this timeframe, we gathered 167 self-reported fractures previously validated from patient records by the OSTPRE study, 561 potential humerus fracture events identified in the registers, and 5211 examination series from the PACS.

The gathered data was processed by reading through the radiological reports in PACS, analyzing the register traces, and cross-checking the events between the data sources. This resulted in a gold standard of 685 fracture events, corresponding to an incidence rate of 359 fractures/100,000 person-years during the 19-year period. The incidence rate changed over the years: from 2004 to 2010, it was 223; from 2011 to 2016, it increased to 429; and from 2017 to 2022, it further increased to 495. The OSTPRE questionnaires from 2004, 2009, 2014, and 2019 covered 24.4% of these gold-standard fractures. The register data covered 67.6% of the fractures across the entire study period. On a yearly level, the register coverage notably improved after the introduction of the Avohilmo register in 2011 (Fig. 2). The average register coverage increased from 50.8% in the period between 2004 and 2010 to 73.7% between 2011 and 2022.

The radiographs in PACS covered 96.9% of the complete gold standard, 88.3% in the early years from 2004 to 2010, and 100.0% between 2011 and 2022. In PACS data, fractures were assessed based on the original radiology reports, when possible, but 91 cases required a retrospective review of the images.

The algorithmic fracture identification results were only assessed based on the years from 2011 to 2022. This period better represents the current situation with both registers (Hilmo and Avohilmo) operating and more comprehensive PACS integration compared to 2010 and earlier years. The complete table of annual analysis results from 2004 to 2022 is provided as supplementary material (Table SI2).

From 2011 to 2022, the traditional register analysis combining both registers covered 73.7% of the gold-standard fractures with a false discovery rate (FDR = false positives / (true positives + false positives)) of 8.4% (Table 1). Registers&PACS algorithm A, requiring a radiography visit to support the registered diagnosis code S42.2, reduced the false discovery rate to 4.4% while maintaining the coverage of 73.7%. Registers&PACS algorithm B, extending to the more generic fracture diagnosis codes (S42, S42.3, and L76) with two radiography visits, improved the coverage to 81.0% with an FDR of 7.4%.

For identifying proximal humerus fractures using only the radiography visits data, the existence of a single radiography examination was insufficient as, despite providing complete coverage, it resulted in an 86.3% false discovery rate. The PACS 2+ algorithm provided a coverage of 83.6% but still a notably higher FDR (26.3%) compared to the register-based algorithms. Increasing the number of required visits from two to three in the PACS 3+ algorithm resulted in a reduced coverage of 67.2% and an FDR of 19.4%. Among all the proposed algorithms, the Registers&PACS algorithm B provided the best balance between sensitivity and precision with an F1 score (F1 = 2 × true positives / (2 × true positives + false positives + false negatives)) of 86.4%.

Discussion

In this study, we investigated different ways of identifying proximal humerus fractures from routinely collected administrative data. The methods using the registers and radiological image archive were evaluated against a gold standard of

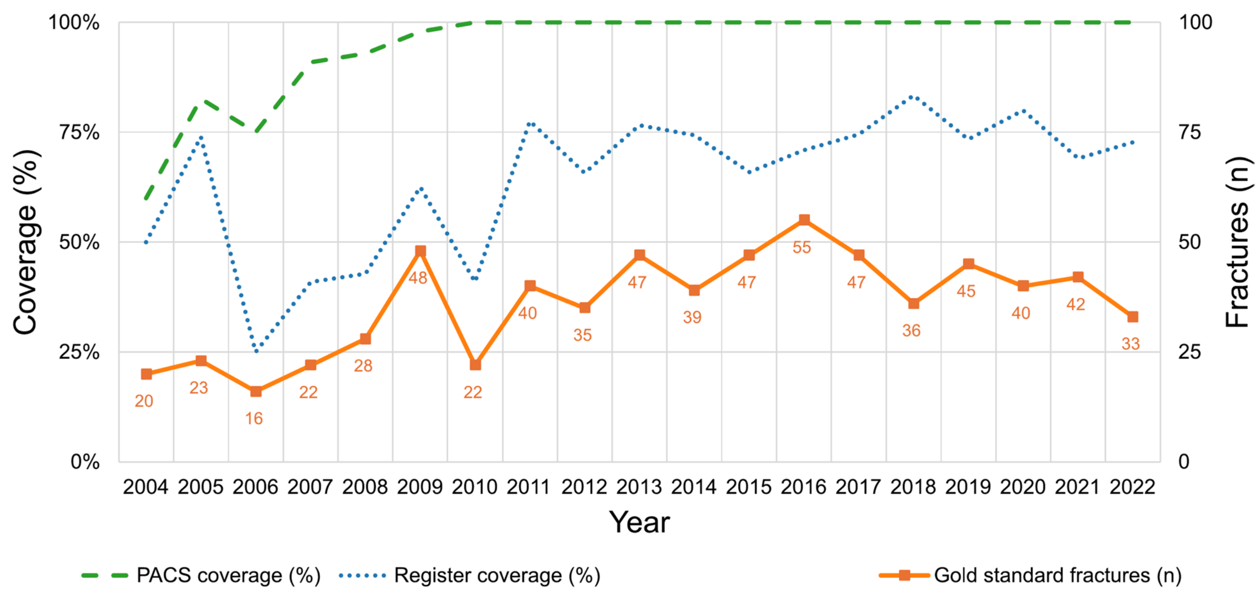

Fig. 2 Yearly gold-standard fracture count (right *y*-axis) and their coverage percentage (left *y*-axis) in the registers and the image archive (PACS). The regional PACS was taken into use in 2003, but it took until around 2010 before it covered all public healthcare providers in the region. The Register for Primary Health Care Visits (Avohilmo) started gathering data from primary care outpatient visits in 2011, which is reflected in the stabilized register coverage in the following years

Table 1 Coverage and false discovery rates for different data sources and algorithms

	Gold standard 2011–2022: 506 fractures				
	True positives	Coverage	False positives	False discovery rate	F1 score
Registers combined (Hilmo + Avohilmo) (S42.2)	373	73.7%	34	8.4%	81.7%
Registers&PACS algorithm A (S42.2 & radiography visit)	373	73.7%	17	4.4%	83.3%
Registers&PACS algorithm B (S42.2 & ≥ 1 rad. visit) OR (S42/S42.3/L76 & ≥ 2 rad. visits)	410	81.0%	33	7.4%	86.4%
Humerus radiography visit in PACS	506	100.0%	3190	86.3%	24.1%
PACS 2+ algorithm (≥ 2 radiography visits)	423	83.6%	151	26.3%	78.3%
PACS 3+ algorithm (≥ 3 radiography visits)	340	67.2%	82	19.4%	73.3%

fractures from 2004 to 2022 derived from various sources: self-reports, radiological reports, national registers, and patient records. The analysis revealed limitations in the traditional register-based fracture identification, especially in the early years of the study period. In contrast, the image archive provided almost complete coverage but posed challenges in excluding false positives. We demonstrated that by combining register and radiography visits data, we can improve the accuracy of automated fracture identification, improving the coverage from 74 to 81% while reducing the false discovery rate from 8 to 7%.

The results complement our previous research on wrist fractures [4], contributing to the aim of identifying all types of fragility fractures for large datasets automatically. Since wrist and proximal humerus fractures are largely treated in outpatient care, their accurate identification highly depends on the completeness of system integrations and the consistency of reporting practices among healthcare providers. Compared to hip fractures treated in specialized health care, reliable identification of these fracture types requires more sophisticated algorithms that combine data from multiple sources.

This study's proposed algorithms for proximal humerus fractures outperform the traditional register analysis but are somewhat less effective than our previous methods for wrist fractures. There are two main reasons for this. Firstly, the treatment of wrist fractures typically follows a more consistent and distinguishable pattern of radiographic examinations [21]. In humerus fractures, the number of radiography visits and the time between them vary more than with wrist fractures [12, 22]. Secondly, wrist radiographs are mostly taken for fracture diagnostics, whereas proximal humerus radiographs serve diverse diagnostic purposes related to, for example, arthrosis, shoulder dislocation, and fractures of other bones. Registered diagnosis codes for these other conditions were sparse making their exclusion difficult.

Nevertheless, the radiography visits data can be used to reduce certain types of false positives occurring in traditional register analysis. For instance, proximal humerus fractures can show post-fracture symptoms even years after the fracture. This often results in a registered visit with the same diagnosis code but without a new radiographic examination. Also, incorrectly reported proximal humerus diagnosis codes were found in cases of prosthesis control, fractures in the distal end or diaphysis of the humerus, and even in fractures of different bones. Algorithms requiring humerus radiography in addition to the registered diagnosis cleared out many of such false positives. This approach also enabled us to extend the analysis to the more generic fracture diagnosis codes S42 and L76 and even to the humerus shaft fracture code S43.4 when they were associated with two or more humerus radiography visits. A detailed analysis of false positives for each algorithm is provided in the supplementary material (Table SI3).

Since the radiography visits data proved most efficient when used in combination with the registered diagnosis codes, the coverage of the national registers remains crucial. The introduction of the Register for Primary Health Care Visits (Avohilmo) had a positive effect, as our annual analysis indicated. However, the register coverage after 2011 was still notably lower in humerus fractures (73.7%) than in wrist fractures (81.0%). The discrepancy could be explained by the difference in the diagnosis codes and the difficulty of accurately locating humerus fractures. Some healthcare providers still use the ICPC2 standard, and while a specific ICPC2 code (L72) exists for wrist fractures, proximal humerus fractures must be reported with the generic code (L76) indicating "other fracture." This code is ineffective for traditional register analysis as it encompasses various unrelated fracture types. Misreported fractures were also observed in ICD-10 codes, with some proximal humerus fractures reported as humerus shaft fractures (S42.3) or distal humerus fractures (S42.4). These may have resulted from initially mislocating the fracture or errors in data entry.

We acknowledge certain limitations in this study. In the early years of the study period, some fractures may be missing from the gold standard as both the register and PACS integrations were incomplete, and the self-reports had limited coverage. Nevertheless, the incidence calculated from our gold standard aligns well with previous literature [16, 18], although comparison between studies is challenging due to differences in fracture registering, study design, and environmental risk factors. Furthermore, as our access was to the regional PACS system, this study is geographically constrained to North Savo and only to participants who resided in the area during the study period. Local differences in the organization of care may affect the results. However, future research could utilize the proposed algorithms to identify fractures from the National Patient Data Repository, which will gather electronic patient data across the country. Also, while some adaptation may be necessary when transferring our methods to registers and image archives in other countries, the approach of combining different administrative data sources and algorithmically adjusting the sensitivity and specificity according to research purposes could work in many data environments worldwide.

While our proposed identification algorithm reached a coverage of 81%, it is also noteworthy that the PACS system did contain radiographs for all the gold-standard fractures between 2011 and 2022. In 91.9% of these cases, the fracture finding could be determined from the written report without image review. Hence, the accuracy of fracture identification can be further refined through the manual effort of reading radiological reports, by utilizing natural language processing techniques or by detecting fractures directly from the images.

Conclusion

Fragility fractures hold considerable importance in osteoporosis research due to their significant impact on morbidity and mortality. With the increasing availability of nationwide electronic patient data, the need for automated fracture identification is growing. Proximal humerus fractures, often treated in outpatient care, pose challenges for traditional register-based identification as the reporting of the diagnostic codes is neither comprehensive nor reliable. The proposed algorithmic approach of combining data from the registers and radiological image archives improves the accuracy of identification. This contributes to the broader goal of automatically identifying all types of fragility fractures in extensive administrative datasets.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s00198-025-07414-3.

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Data availability Data are available upon reasonable request.

Declarations

Conflict of interest None.

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