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ORIGINAL RESEARCH

Combining Register and Radiological Visits Data Allows to Reliably Identify Incident Wrist Fractures

Tomi Nissinen[1,2], Reijo Sund[3], Sanna Suoranta[2,4], Heikki Kröger[3,5], Sami P Väänänen[1,2]

[1]Department of Technical Physics, University of Eastern Finland, Kuopio, Finland; [2]Department of Clinical Radiology, Kuopio University Hospital, Kuopio, Finland; [3]Kuopio Musculoskeletal Research Unit, Institute of Clinical Medicine, University of Eastern Finland, Kuopio, Finland; [4]Division of Clinical Radiology, Institute of Clinical Medicine, University of Eastern Finland, Kuopio, Finland; [5]Department of Orthopaedics, Traumatology and Hand Surgery, Kuopio University Hospital, Kuopio, Finland

Correspondence: Tomi Nissinen, Department of Technical Physics, University of Eastern Finland, PO Box1627, Kuopio, 70211, Finland, Tel +358 40 756 9303, Email tomi.nissinen@uef.fi

Purpose: To evaluate how comprehensively wrist fractures can be tracked from the national medical registers, and to propose a method for complementing the register data using time stamps of wrist radiography visits recorded in the radiological image archive.
Patients and Methods: For the Kuopio Osteoporosis Risk Factor and Prevention Study (OSTPRE) cohort of 14220 post-menopausal women, we analysed the data from the Care Register for Health Care, Register for Primary Health Care Visits, self-reports, radiological image archive PACS, and patient records to identify the wrist fractures occurred between 2011 and 2021. Using this gold standard of fractures, we validated the coverage of the registers and image archive and created algorithms to automatically identify fracture events from the registers and/or metadata of wrist radiography visits.
Results: We show that wrist fractures cannot be comprehensively identified based on national registers. To remedy this, our proposed method of combining register and image archive data can lift the coverage from 81% to 94% and reduce false discoveries from 6% to 2%.
Conclusion: The proposed method offers a more reliable way of gathering fracture information. Comprehensive fracture identification is essential in many research settings, such as incidence statistics, prevention studies, and risk assessment models.
Keywords: medical register, image archive, picture archiving and communication system, PACS

Introduction

Wrist Fractures

Fragility fractures, commonly caused by falls, are a major health concern for the elderly. In Europe, 4.3 million fragility fractures occurred in 2019,[1] and the incidence is increasing as the population ages. In addition to delivering care, it is important to monitor the incidence of fractures to evaluate the effectiveness of care and prevention measures like fracture risk assessment and prescription of osteoporosis drugs. In Finland, 40000 fragility fractures are reported each year, with 12000 of these occurring in the distal radius and ulna.[2] Other common sites include the hip, spine, and proximal humerus, but wrist fracture is the most prevalent of fracture types.[3,4] Yet, in fracture-related research, many studies focus on hip fractures as their outcome of interest. This is partly because of its severity but also because the data is more conveniently available. In Finland, hip fractures are treated in tertiary healthcare while wrist fractures are often treated in local health centres, which are known to be more heterogenous in their data reporting practices.[5] This causes incompleteness and bias when using data from the national medical registers and should be recognized as a limitation in epidemiological fracture research.

Registers and Image Archives

The Care Register for Health Care (Hilmo) and its predecessor, Finnish Hospital Discharge Register contain data on the activities of health centres, hospitals and other Finnish institutions providing inpatient health care since 1969, and for hospital outpatient visits since 1998.[6] The focus of the register is on the use of health care services rather than on the

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epidemiology of diseases. Still, as an easily available nationwide data source, it has been utilized by many fracture studies in Finland.[2,5,7–9]

To incorporate fractures treated in primary health care, Hilmo must be used together with the Register for Primary Health Care Visits (Avohilmo). Avohilmo has collected data on public primary health care delivered in Finland since 2011, but the coverage has been building up over the years.[10] Some fracture studies have used Avohilmo to extend their research data,[8] but few have acknowledged its limitations. For example, the data are sent from health centres to the register controller automatically, but the recording rates of diagnostic codes in the primary systems have been from 72% to 85% in recent years.[11,12] Furthermore, the reported code does not always reflect the final diagnosis. If the preliminary diagnosis is corrected during the treatment episode, the previous diagnosis codes are not updated retrospectively.

The radiology departments in the Finnish healthcare system follow the workflows recommended by the IHE (Integrating the Healthcare Enterprise®) international initiative.[13] The radiological information is stored in centralized radiological information system (RIS) and picture archiving and communication systems (PACS) that gather radiological information from all public healthcare providers in the region. Primarily, this ensures that images and radiology reports are available for all healthcare professionals, but it also provides a potential source of fracture information parallel to the medical registers.

Wrist Fracture Treatment Episode

The treatment episode of a wrist fracture starts when a patient experiences pain in the wrist area after trauma and ends up receiving medical help at the local healthcare provider. The clinician first gathers information from the patient and performs physical exams. When a fracture is suspected, a standard wrist x-ray series is acquired. If the findings suggest a fracture, the clinician makes the decision on operative or non-operative treatment. Most wrist fractures can be conservatively managed in outpatient care.[14] The initial treatment procedure commonly involves closed reduction and placing a cast to minimize the risk of re-displacement. Surgical intervention is considered in the case of an unstable or displaced fracture.[15] Several radiological examinations take place during the diagnosis and treatment process. In the conservative treatment, a second x-ray is taken through the cast to ensure that the reduction was successful. Then, in routine follow-up, radiographs are taken 1, 2, and 5 weeks after placing the cast. For patients over 65 with a not particularly active lifestyle, routine follow-up radiographs may be skipped, as they rarely affect the treatment.[14]

Prior Studies

Algorithmic approaches to identify fracture events from routinely collected national data sources have been proposed in different countries.[16,17] However, there is wide variation in fracture outcome definitions used with administrative healthcare data.[18] Methods for distinguishing incident fractures from readmissions in register data have been discussed in a study on hip fractures.[19] Validation studies[20,21] have compared the data from questionnaires and registers to find that, as with register data, also survey data has its limitations and bias. Koski et al[5] studied the incidence of fragility fractures in Central Finland between 2005 and 2006, before the introduction of Avohilmo, and observed the limited register coverage of wrist fractures. Until now, the recent coverage and accuracy of fracture data in the Finnish registers, especially regarding outpatient care, and how to complement it with information from radiological metadata, has not been studied.

Aims

The aim of this study was first to track all wrist fractures for the OSTPRE cohort using all available sources including registers, self-reports, radiology reports and patient records. Then, the objective was to evaluate how comprehensively the fracture events can be identified from the national medical registers. Finally, we aimed to discover how fracture events from the registers could be complemented automatically from the time stamps of wrist radiography visits recorded in the radiological image archive.

Materials and Methods

Data Collection

The research cohort of Kuopio Osteoporosis Risk Factor and Prevention Study (OSTPRE) has been followed since 1989.[22] It comprises 14220 women who were aged 47 to 56 years and residents of the Kuopio Province, Finland at the time. The participants have reported their health information, including occurred fractures, through postal enquiries every 5th year during the OSTPRE study. Additional fracture-related information was gathered from the national medical registers Hilmo and Avohilmo and the radiological image archive PACS. Our analysis focused on the years between 2011 and 2021 because Avohilmo has been in use nationwide since 2011, and 2021 was the last full year of register data available to us. In 2011, there were 12013 participants alive in the cohort.

The study had access to the PACS archive covering the North Savo region where the cohort participants originally lived. For better comparability between data sources, a subcohort was created of the 10355 participants whose home was within the PACS coverage area throughout the analysis period or until their death. We report the results for both the full cohort and the North Savo subcohort.

Establishing Gold Standard

The fractures occurring in the distal end of the radius or ulna are considered wrist fragility fractures.[23] We gathered potential events of such fractures from the medical registers, self-reports, and radiological image archive. The gold standard was then established by validating the events from different data sources (Figure 1).

First, we included the previously validated self-reported fractures from the OSTPRE questionnaires.[24] Secondly, we used wrist radiography data in the PACS and went through all the original radiology reports with a procedure classification[25] code for wrist X-ray (ND1AA), extensive wrist X-ray (ND1BA), or both wrists X-ray (ND1DA). Our radiologist read retrospectively the radiographs with missing or unclear reports. Fracture events with either an original or retrospective fracture report by a radiologist were included in the gold standard.

Thirdly, we identified fracture events from the medical registers Hilmo and Avohilmo using ICD-10[26] diagnosis codes S52.5 and S52.6 and ICPC2[27] code L72. The register events that agreed with a self-report or a radiology report were included in the gold standard. For the cases with a fracture diagnosis in the register but no matching self-reports or radiographs, we performed a more detailed investigation into patient records and register history (see Supplementary Materials for details).

Automated Fracture Identification

To study how the fracture events could be identified automatically from the registers or the metadata of radiography visits without using the written reports or examining the images themselves, we created and evaluated several rule-based algorithms. The choice of algorithm depends on the availability of different data sources as well as the research purpose, as there is always a trade-off between sensitivity and specificity. Some studies may want to explore as many fractures as possible, whereas in other studies it is important to minimize false positives.

PACS Algorithms

PACS 2+ algorithm explores fracture events from radiography metadata by finding patterns of two or more wrist radiography visits within 60 days. The hypothesis behind this was that if the initial examination is followed by another, there is usually at least a suspected fracture.

PACS 3+ algorithm expects that a fracture case involves at least three radiographic examinations. Two examinations during the main visit, before and after casting or surgery, and at least one follow-up. This algorithm was assumed to be less sensitive compared to PACS 2+ as the third image may be absent for reasons like missing data or follow-up in another institution. On the other hand, it should be more specific to the recommended wrist fracture treatment procedure.

Algorithms Combining PACS and Registers

PACS&register algorithm A includes all the events found by PACS 3+ algorithm and adds the PACS 2+ events with a wrist fracture diagnosis in the register within ± 60 days from the PACS event. This algorithm was designed to extend

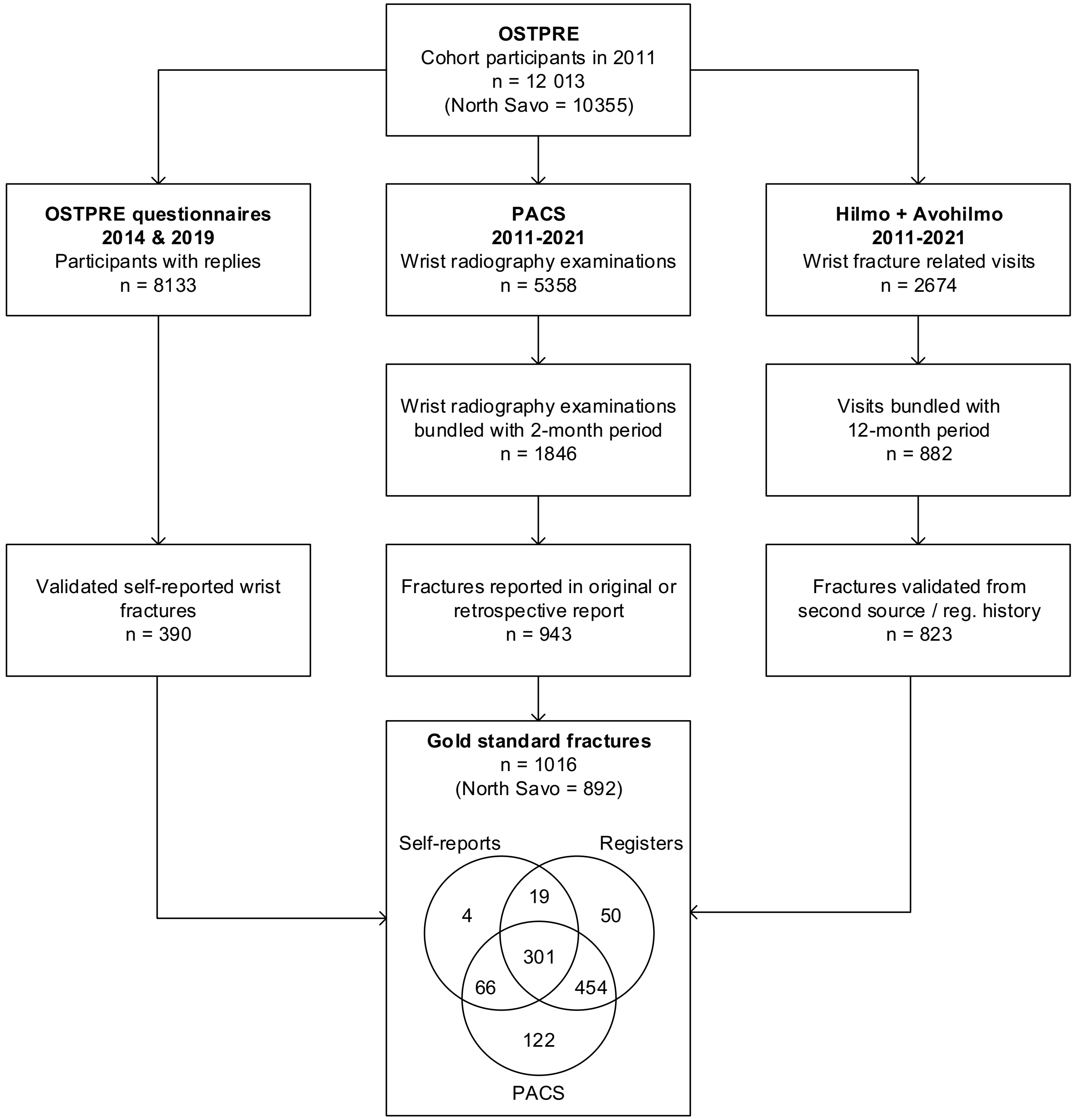

Figure 1 Flowchart for establishing the gold standard of wrist fractures for the participants of the OSTPRE study cohort from 2011 to 2021. The Venn diagram in the bottom box illustrates the overlap between different sources of fracture events in the gold standard.

the coverage of PACS 3+ by including some of the less certain PACS 2+ events that are supported by a fracture diagnosis in the registers.

PACS&register algorithm B includes all the events found by PACS&register algorithm A and adds the register events that have three or more fracture diagnosis codes on separate dates within 60 days. This algorithm was created to test if the register data could fill in the cases of missing PACS data.

Results

Data Analysis

For the study population of 12013 participants, the raw register data consisted of 2674 contacts with a wrist fracture diagnosis code and a date between January 1st, 2011, and December 31st, 2021. Excluding readmissions with a 12-month clearance period (see Supplementary Material Figure S1 for details), 882 potential wrist fracture events were identified from the registers. In addition, the study period included 390 validated self-reported fractures from the OSTPRE study and 5358 wrist radiography examinations from PACS. With a clearance period of 60 days, the PACS data constituted 1846 examinations indicating potential fractures. Most examinations had valid radiological reports, but 131 were reviewed retrospectively by our radiologist due to missing or unclear original report.

After cross-validating the radiology reports, self-reports, and register events and confirming the unclear cases from the patient records and register history, 1016 fracture events formed the gold standard in our study. This includes all fractures found, irrespective of the clearance periods. Among the 12013 female participants aged 79 years on average, over the period of 11 years, the gold standard corresponds to an incidence rate of 883 fractures / 100,000 person-years.

The Hilmo register data covered 44.2% of the gold standard fractures, whereas Avohilmo covered 65.3%. Together the register data covered 81.0% of the gold standard (Table 1) and indicated 59 false positives. This corresponds to a 6.7% false discovery rate (FDR = false positives / (true positives + false positives)). To analyse the reporting of diagnosis codes, we also checked the registers for any contacts regardless of diagnosis codes within 14 days starting from the gold standard fracture events. It revealed that the registers had some patient contact for 98.3% of the fracture events, but only 74.8% had been reported with a wrist fracture diagnosis code (Figure 2).

The OSTPRE questionnaires from the years 2014 and 2019 yielded replies from 69.3% and 50.2% of the alive participants, respectively. The self-reports from these surveys covered 38.4% of the gold standard fractures. Of the self-reported fractures, 82.9% were also in the registers, and 94.1% had radiographs in the PACS. Of all the gold standard fractures, 92.8% had at least one wrist radiographic examination in the PACS.

The North Savo subcohort of 10355 participants (86.2% of the full cohort), with an average age of 79 years, constituted 892 (87.8%) of the gold standard fractures, corresponding to an incidence rate of 896 fractures / 100,000 person-years. Compared to the full cohort, the analysis of this subcohort indicated similar level coverage rates for the nationwide registers (80.6%) and self-reported data (40.0%). However, the fracture coverage of the PACS archive increased to 99.2%.

Table 1 Coverage and False Discovery Rates for Different Data Sources and Algorithms

	Full Cohort (1016 Fractures)				North Savo Subcohort (892 Fractures)			
	True Positives	Gold Standard Coverage	False Positives	False Discovery Rate	True Positives	Gold Standard Coverage	False Positives	False Discovery Rate
Hilmo register	449	44.2%	18	3.9%	380	42.6%	12	3.1%
Avohilmo register	663	65.3%	47	6.6%	592	66.4%	39	6.2%
Registers combined (Hilmo + Avohilmo)	823	81.0%	59	6.7%	719	80.6%	47	6.1%
Wrist radiograph in PACS	943	92.8%	903	48.9%	885	99.2%	834	48.5%
PACS 2+ algorithm	910	89.6%	101	10.0%	855	95.9%	94	9.9%
PACS 3+ algorithm	824	81.1%	10	1.2%	775	86.9%	8	1.0%
PACS&register algorithm A	882	86.8%	18	2.0%	828	92.8%	16	1.9%
PACS&register algorithm B	926	91.1%	23	2.4%	838	93.9%	20	2.3%

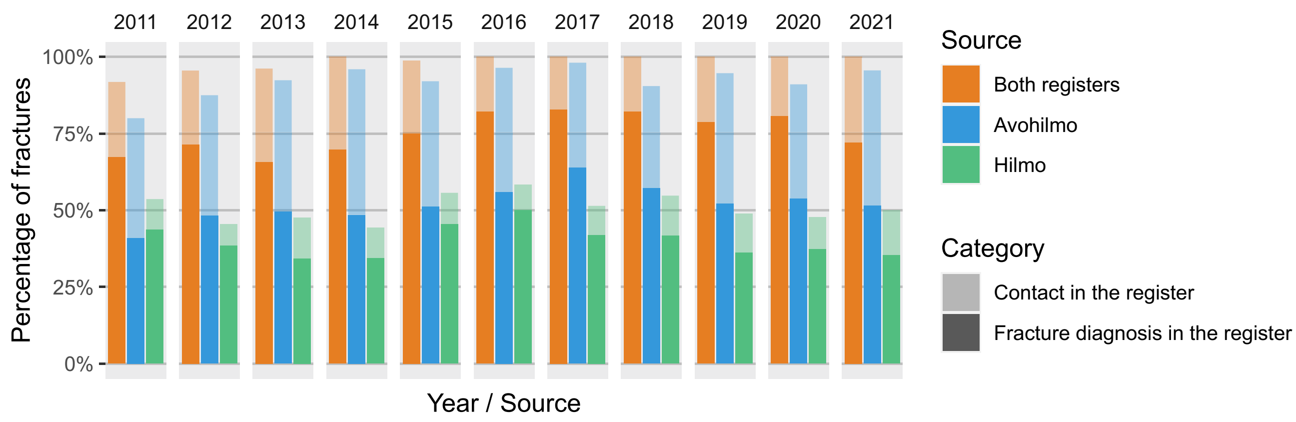

Figure 2 The yearly register coverage of gold standard fractures. Since 2014, almost all the fractures have some contact in Hilmo or Avohilmo within 14 days from the index date but the recording rate for diagnostic codes is incomplete.

Algorithm Performance

PACS 2+ algorithm, detecting series of two or more wrist radiography visits within 60 days, covered 89.6% of the gold standard fractures with a 10.0% false discovery rate, whereas PACS 3+ had a lower (81.1%) gold standard coverage but also a lower FDR (1.2%). In the North Savo subcohort, PACS 2+ covered 95.9% of the fractures with a 9.9% FDR, whereas PACS 3+ covered 86.9% of the fractures with a 1.0% FDR.

PACS&register algorithm A, extending PACS 3+ algorithm with the PACS 2+ events with a fracture diagnosis in the register, covered 86.8% of the gold standard fractures with a 2.0% FDR. In the North Savo subcohort, it had a 92.8% fracture coverage and a 1.9% FDR. Compared to PACS 3+, PACS&register algorithm A improved the coverage at the cost of more false discoveries.

PACS&register algorithm B, extending PACS&register algorithm A with the register events having three or more fracture-coded contacts, covered 91.1% of the gold standard fractures with a 2.4% FDR. In the North Savo subcohort, it produced a coverage of 93.9% and a false discovery rate of 2.3%. Compared to PACS&register algorithm A, algorithm B improved the coverage in the full cohort with a minor increase in FDR, but in the North Savo subcohort, this improvement was smaller.

Discussion

In this paper, we formed the gold standard for wrist fractures of a large patient cohort using information from several data sources, including patient registers and radiological reports. Then, we proposed an automated method to collect wrist fracture data efficiently and more accurately compared to traditional register analysis. We showed that the method, combining information from the radiological image archive and national registers, identifies more fractures (93–94%) than register analysis (81%) and reduces the false discovery rate from 6% to 2%.

Our main contribution is the straightforward approach for collecting fracture data from large datasets without manual review. Apart from access to examination codes and time stamps in the regional image archives, the rule-based algorithms do not require any specialized tools. By adjusting the algorithm's requirements, we can further improve sensitivity or specificity at the cost of the other, when required by the research purpose. The resulting data can be used to monitor the incidence of fractures (see Supplementary Material Table S2 for details) as well as to identify individual fracture events. Accurately dated fracture outcomes are valuable, for example, in the training of supervised machine learning models.

The present study draws attention to the limitations in the traditional data collection methods for epidemiological fracture research, especially regarding fractures treated in outpatient care. While the introduction of Register for Primary Health Care Visits (Avohilmo) has improved the situation compared to the reported 60% coverage in 2005 and 2006,[5] our analysis revealed that still only 75% of the new wrist fractures had proper diagnosis codes registered near the index date. As the most prevalent fragility fracture type, wrist fractures constitute a major part of the outcome data in prevention studies. Also, wrist fractures are an important predictor of future fragility fractures[6] and thus deserve their own research focus.

The performance of the proposed algorithms depends on the coverage of the image archive, as the higher gold standard coverages in the North Savo subcohort compared to the full cohort indicated. To improve the performance, radiological data should be collected from all PACS systems in the country. In Finland, however, all electronic patient data, including radiological images, will be gathered in the national Patient Data Repository[28] in the future. Then, the proposed algorithms could identify fractures across the country from this single source.

Despite the available data, there were cases where the occurrence of fracture could not be automatically determined with the algorithms. For example, in some fractures, the patient had sought care so late that the new bone formation had already begun. At this point, it was often too late for any effective treatment, so there was no follow-up. On the other hand, false positives resulted mainly from other findings like arthrosis and rheumatics or suspected fractures that required some follow-up before reaching the diagnostic conclusion (see Supplementary Material Table S1 for detailed analysis of false positives). Further performance improvements in these cases could possibly be achieved by utilizing image analysis techniques for the radiographs or natural language processing for the radiology reports.

The cohort population in this study consists of only post-menopausal women, but the proposed method is more widely applicable since the treatment period for wrist fracture does not differ significantly between patient groups. Some adaptation may be required for other countries as the method was developed based on the Finnish healthcare system. However, Finnish radiology departments follow the IHE recommendations, meaning that the workflows and examination practices should be comparable to other member countries of the initiative. Also, the results of this study could inspire a similar approach to be used with different administrative data sources such as health insurance databases.

Conclusion

Comprehensive wrist fracture data forms a significant part of the information needed in fracture research. Methods to expand data coverage from specialized healthcare to primary care can open new research prospects and reduce bias in the available data. The quality of output variables is crucial in prevention studies as well as in the development of data-driven prediction models. Our proposed method offers an additional source for wrist fracture data acquisition, improving both the coverage and accuracy of the established practices in the field.

Ethics Approval Statement

Collection of the data used in this project has been approved by a legible ethical authority. All patient data was pseudonymized and treated such that there was no risk in violating the privacy of the patients. Ownership of the data belongs to PI and collaborators. The use of the OSTPRE dataset was approved by the Kuopio University Hospital's Ethical committee.

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Disclosure

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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