


BMJ Open Cohort profile: CROSS-TRACKS: a population-based open cohort across healthcare sectors in Denmark

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ABSTRACT

Purpose This paper describes the open cohort CROSS-TRACKS, which comprises population-based data from primary care, secondary care and national registries to study patient pathways and transitions across sectors while adjusting for sociodemographic characteristics. **Participants** A total of 221 283 individuals resided in the four Danish municipalities that constituted the catchment area of Horsens Regional Hospital in 2012–2018. A total of 96% of the population used primary care, 35% received at least one transfer payment and 66% was in contact with a hospital at least once in the period. Additional clinical information is available for hospital contacts (eg, alcohol intake, smoking status, body mass index and blood pressure). A total of 23% (n=8191) of individuals aged ≥65 years had at least one potentially preventable hospital admission, and 73% (n=5941) of these individuals had more than one.

Findings to date The cohort is currently used for research projects in epidemiology and artificial intelligence. These projects comprise a prediction model for potentially preventable hospital admissions, a clinical decision support system based on artificial intelligence, prevention of medication errors in the transition between sectors, health behaviour and sociodemographic characteristics of men and women prior to fertility treatment, and a recently published study applying machine learning methods for early detection of sepsis.

Future plans The CROSS-TRACKS cohort will be expanded to comprise the entire Central Denmark Region consisting of 1.3 million residents. The cohort can provide new knowledge on how to best organise interventions across healthcare sectors and prevent potentially preventable hospital admissions. Such knowledge would benefit both the individual citizen and society as a whole.

INTRODUCTION

An increasingly ageing population and limited resources place new demands on society and healthcare.¹ The global population of individuals aged 65+ years is projected to increase from 8.2% in 2015 to 15.9% in 2050, corresponding to >1.5 billion people.² The elderly population has higher needs for healthcare compared with younger citizens.^{3,4} For example, the number of hospital

Strengths and limitations of this study

- The CROSS-TRACKS cohort is a population-based open cohort containing routinely collected data from both primary and secondary care combined with sociodemographic register data.
- The cohort is readily available for research projects: the data sources have already been linked, patient pathways have been identified, and data have been remodelled and prepared for cutting-edge use of artificial intelligence and to enable easier and simpler querying across source systems.
- The cohort is currently limited to the catchment area of Horsens Regional Hospital, but it covers both urban and rural areas and it has a total population of 221 283 individuals by 2018.
- The cohort will be expanded to include additional catchment areas in the Central Denmark Region, comprising a total population of 1.3 million individuals.
- The cohort offers new opportunities for health research by tracking the patients' pathway across healthcare sectors to provide new knowledge on the best way to organise future interventions.

admissions has increased by 45% from 2006 to 2018 among Danes aged 65+ years.⁵ Therefore, Denmark and many other countries have reorganised the healthcare systems; they have reduced the number of hospital beds and shortened the length of hospital stays. The total number of days in a hospital bed has decreased by 16% from 2006 to 2018.⁵ Therefore, an increasing part of the healthcare, treatment and rehabilitation services are provided by general practitioners (GPs) and the municipalities in the primary care setting.

One focus has been directed towards reducing the number of potentially avoidable readmissions.⁶ In the USA, almost 20% of discharged patients are readmitted to hospital within 30 days.⁷ This is costly to the individual citizens and to society. Special attention has

been turned towards potentially preventable admissions and readmissions. These are often seen for ambulatory care sensitive conditions (ACSCs), which comprise conditions that can usually be treated and prevented in the primary care setting.⁸ More than 20% of hospital admissions among elderly US residents in nursing homes are estimated to concern ACSCs.⁹ In Denmark, 15% of all hospitalisations of the elderly population are expected to be preventable.¹⁰ The rates of potentially preventable hospital admissions are high in Denmark compared with other European countries.¹¹ Furthermore, a recent study found higher rates of potentially preventable hospitalisations and readmissions for chronic medical conditions in Denmark compared with the USA.¹² Consequently, there seems to be room for improvement in our approach to preventable admissions and readmissions.

Several interventions have aimed to reduce the risk of readmissions¹³ and to improve the care for discharged patients in the primary care setting.¹⁴ Most of these focused on the pre-discharge period (eg, patient education and discharge planning) or the post-discharge period (eg, follow-up telephone calls and home visits), whereas only few interventions bridged over both sectors (eg, patient-centred discharge instructions and transition coaching). The interventions bridging across sectors were most effective.¹³ This calls for studies of patient transitions across sectors in a population-based setting.

CROSS-TRACKS¹⁵ is an open cohort comprising routinely collected administrative data from primary care, secondary care and national registries. The combined data sources allow us to explore key factors such as socio-demographic characteristics, labour market affiliation, social transfers, home-based nurse care, GP contacts and potential links between these factors and the use of services in secondary care.

The cohort is a valuable tool for studying patient pathways across sectors, including the patterns that characterise potentially preventable hospital admissions. This paper describes the new opportunities in healthcare research that are emerging from the comprehensive CROSS-TRACKS cohort.

COHORT DESCRIPTION

Setting

The tax-funded healthcare system in Denmark provides free access for all citizens to healthcare services. The five Danish regions are the backbone of the healthcare system, and they are responsible for organising and operating the somatic and psychiatric hospitals (figure 1). Furthermore, the regions reimburse GPs and specialists in private practice (eg, physiotherapists, psychologists or dentists) for dispensed prescriptions and services provided.¹⁶ The GPs can refer citizens to a wide range of welfare services (eg, home care and rehabilitation) that are provided in the primary care setting by the 98 municipalities under the regions.¹⁶ The catchment area usually comprises

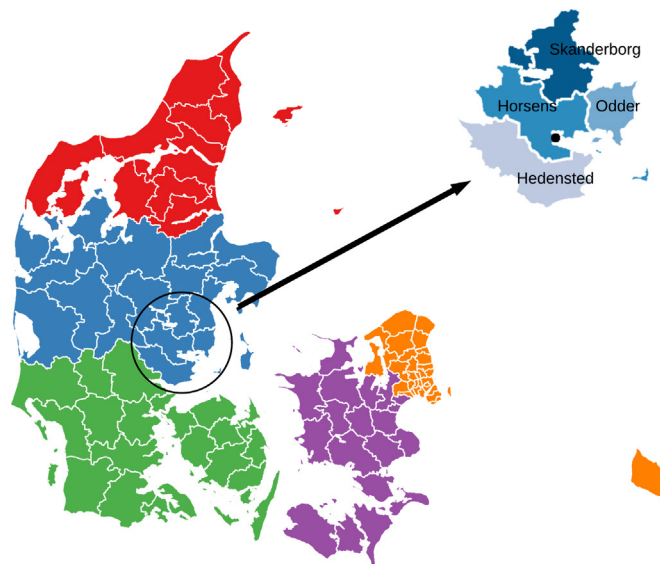


Figure 1 The five Danish regions and the 98 municipalities. The black circle indicates the four municipalities (Hedensted, Horsens, Odder and Skanderborg) included in the CROSS-TRACKS cohort, and the black dot indicates the location of Horsens Regional Hospital.

the municipalities in the geographical area around the hospital.

The GP is the primary entry point into the healthcare system for Danish citizens, and the GP acts as a gatekeeper to secondary care,¹⁷ but the citizens can contact the prehospital directly for emergencies. Citizens have unrestricted access to dental care, which is free of charge for citizens below the age of 18. After hospital discharge, patients may be referred to the GP or a triage manager in the municipality for further treatment, care, or rehabilitation.

All Danish citizens receive a unique identifier at birth or immigration. This number is also referred to as the civil personal register (CPR) number.¹⁸ The CPR number enables electronic linkage for all data in the cohort across registries and databases. The cohort data are securely stored at the data warehouse of the Central Denmark Region in accordance with data protection regulations. The cohort is readily available for research projects as the data sources have already been linked and patient pathways have been identified. Further, the data have been remodelled according to the dimensional modelling principles laid out by Kimball and Ross,¹⁹ to provide a simple and consistent query interface across source systems.

As a rule, only anonymised data without the CPR number is provided to researchers. Researchers will receive an anonymised dataset that has already been linked and tailored to the individual project. Research projects that require additional linkage with other registry data can be provided with the CPR number. However, this is only possible on a secure server. In general, datasets must be securely stored, and the researchers must comply with research ethics guidelines.

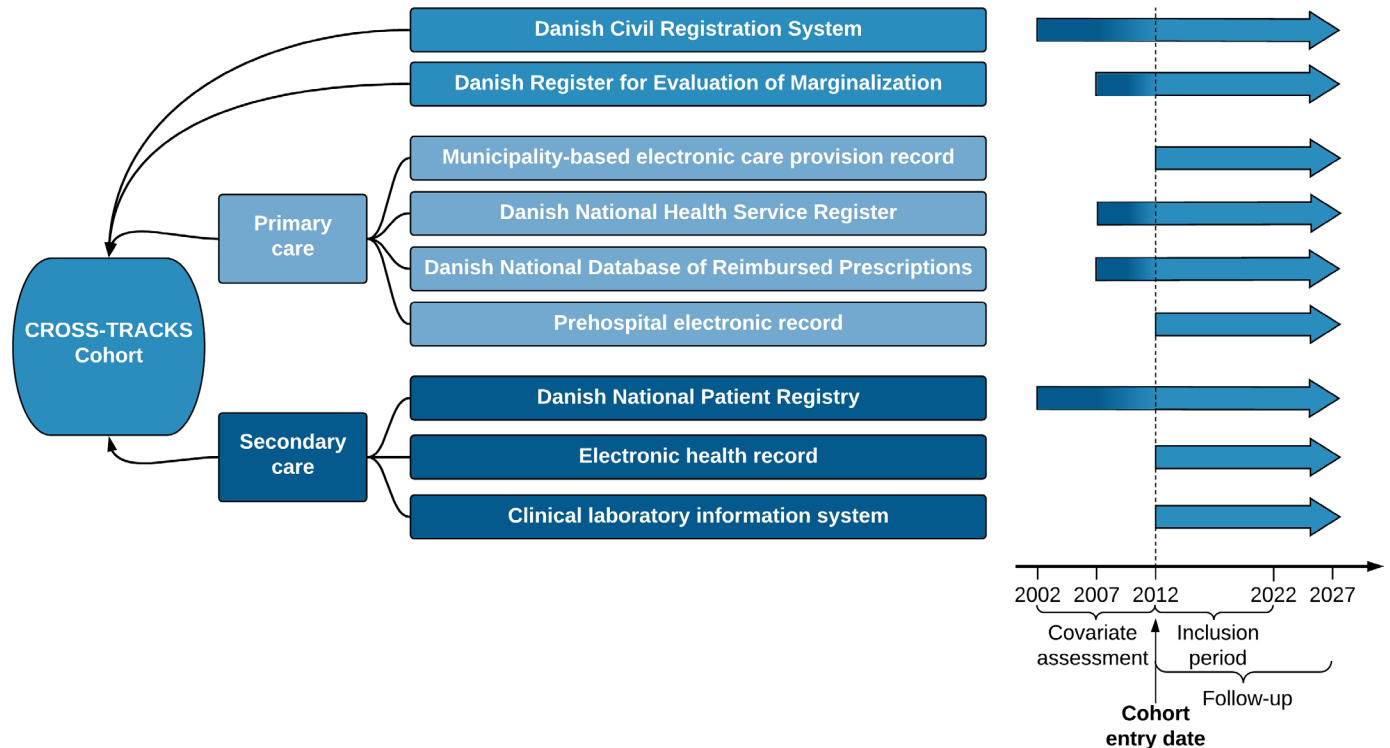


Figure 2 Data availability for the CROSS-TRACKS cohort in Denmark.

Study population

The CROSS-TRACKS cohort consists of all citizens aged 18+ years residing in the catchment area of Horsens Regional Hospital, which comprises Hedensted, Horsens, Odder and Skanderborg municipalities (figure 1). The inclusion period started on 1 September 2012 (cohort entry date) and will last through 2022 (figure 2). Individuals are included on their 18th birthday or when moving to one of the four included municipalities. Individuals are followed from the date of inclusion until 5 years after the end of the inclusion period (31 December 2027) or date of death. Individuals moving away from these municipalities are followed for 5 years after the date of moving.

Patient characteristics are time-dependent because disease develops over time, and this affects the number and frequency of contacts with the healthcare system. The use of nationwide data sources ensures optimal adjustment for potential differences in patient characteristics, even for individuals living outside the included municipalities during part of the follow-up period. Moreover, we use look-back periods of lengths 5–10 years to assess covariates prior to cohort entry date (figure 2).²⁰

Data collection

Individuals are included in the cohort according to the inclusion criteria shown in the flow chart in figure 3.

Administrative and health registries

The CPR number originates from the Danish Civil Registration System (CRS),¹⁸ which also provides date of birth, gender, vital status, civil status, migration and place of residence. The CRS is updated on a daily basis with

information on vital status and place of residence; this ensures complete follow-up for all individuals.

Weekly recordings of social benefits and other transfer incomes are retrieved from the Danish Register for Evaluation of Marginalisation (DREAM).²¹ DREAM can be used to categorise individuals into unemployed, on sick leave, receiving part-time benefit, receiving disability pension, or receiving retirement pension.²²

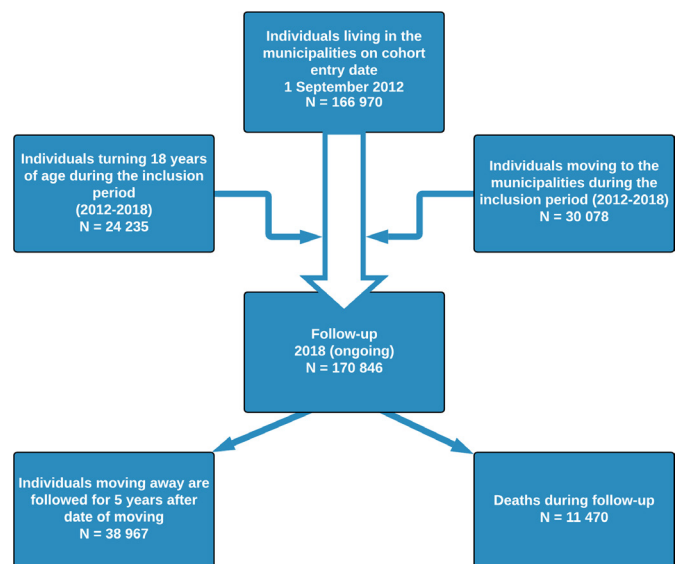


Figure 3 Flow chart of individuals included in the CROSS-TRACKS cohort in Denmark 2012–2018.

Primary care

The municipality-based electronic care provision record (ECPR) holds data on the health services granted to the citizens. These services comprise municipality-based practical help, rehabilitation assistance, personal care and home visits by a community nurse. The data includes the period (start and end dates) and total amount of time assigned to the services.

The Danish National Health Service Register holds information on contacts with healthcare professionals (eg, GP, dentist), type of consultation (eg, ordinary consultations, home visits, telephone consultations, electronic consultations), services provided (eg, paraclinical examinations, vaccination, pregnancy) and laboratory tests performed.²³

The Danish National Database of Reimbursed Prescriptions contains detailed information on prescribed drugs that are partially reimbursed by the regions. This includes information on date of the redemption, number of pills, dose, number of defined daily doses, name and type of drug according to the Anatomical Therapeutic Chemical classification system.²⁴

The prehospital electronic record holds information on treatment and transportation of patients by ambulance, medical cars or helicopters. Registrations include urgency level, date and time of departure and arrival, treatments, medications and a free-text field for additional information that may help ensure optimal transfer of patients to the hospital.²⁵

Secondary care

The Danish National Patient Registry (DNPR) encompasses all hospital contacts, including admission date, discharge date and outpatient visits. Diagnoses, surgical procedures and examinations are registered according to the International Classification of Diseases.²⁶ The main reason for each hospital contact is registered as the primary diagnosis, whereas secondary diagnoses are stated as other diseases in relation to the contact. Diagnoses registered in the DNPR can be used to identify individuals admitted to hospital with a primary ACSC-related diagnosis. In addition, the Charlson Comorbidity Index (CCI) score is calculated based on 19 conditions.²⁷

The electronic health record (EHR) in the Central Denmark Region consists of healthcare-related registrations linked with date and time. The DNPR is based on registrations in the EHR, but this record contains additional data that are not transferred to the DNPR. This includes registrations on triage, patient's pulse, blood pressure, respiration frequency and microbiology test results. Some of these are used for early detection of critical illness. The EHR can also be used to identify patient-related lifestyle factors, such as diet, smoking and alcohol habits and physical activity. Furthermore, hospital-based drug treatment is registered in the EHR by the doctors prescribing the drug and the nurses administering the drug by dispensing the medicine to the patients.

The clinical laboratory information system consists of test results from blood and urine samples drawn by health professionals (in both primary care and hospitals) and analysed in clinical laboratories.²⁸ Registrations include date of sample, health professional or hospital department requesting the analysis, requested assay or biomarker and corresponding nomenclature, properties and units code.

An overview of data sources and availability can be seen in [figure 2](#) and [table 1](#). The codes used to extract the characteristics of citizens can be found in online supplemental material 1.

Although the EHR data in the data warehouse of the Central Denmark Region is updated on a daily basis, the combined cohort consisting of all data sources is only updated annually. The cohort is dynamic in the sense that the data quality is continuously improved as new research projects build on new sections of the cohort. See online supplemental material 2 for a description on how registrations on body mass index (BMI) was cleaned before use and online supplemental material 3 for a description on cleaning of blood pressure registrations.

Follow-up

Individual-level information during follow-up on diseases, treatments and administrative registrations is provided from the administrative and health registry data included in the cohort. Individuals are followed with respect to these registrations and their relevance to the study question for 5 years after the end of the inclusion period or from when they move away from the municipalities. Date of emigration or date of death is provided from the CRS.

Population characteristics

On the cohort entry date, 166 970 individuals aged 18+ years resided in the four municipalities. From 1 September 2012 through 2018, 24 235 individuals turned 18 years of age, and 30 078 moved to one of the municipalities. This yields a total population of 221 283 individuals in the open cohort ([figure 3](#)). The main characteristics of citizens in the cohort are shown in [table 2](#). Individuals aged below 18 years appear in the table, but they are not included in the cohort before their 18th birthday.

The catchment area of Horsens Regional hospital contained one health centre (located in Skanderborg), 69 GPs, 20 specialists in private practice, 11 chiropractors, 52 dentists, 45 physiotherapists, 25 podiatrists and 25 psychologists.

The largest municipality was Horsens with 78 758 citizens, corresponding to 36% of the population on 1 September 2012. Skanderborg had 49 160 (22%) citizens, Hedensted had 39 981 (18%) citizens and Odder had 19 493 (9%) citizens. In the beginning of the inclusion period, Horsens was the only urban municipality, but Skanderborg went from rural to urban during the period.

The median age on cohort entry date was 41 years (IQR: 25–58 years) with an equal distribution of gender. The proportion of citizens who were married or living in

Table 1 Administrative and health registries included in the CROSS-TRACKS cohort

Name and type of data source and year of initiation	Description of data source	Main variables	Period of data inclusion in the CROSS-TRACKS cohort
Danish Civil Registration System, ¹⁸ administrative registry, 1968	Information on all individuals residing in Denmark	<ul style="list-style-type: none"> ▶ CPR no (allowing linkage across all data sources) ▶ Date of birth ▶ Gender ▶ Vital status (updated daily) ▶ Civil status (updated daily) ▶ Migration (updated daily) ▶ Place of residence (updated daily) 	1 September 2002–31 December 2027
Danish Register for Evaluation of Marginalisation, ^{21 22} administrative registry, 1991	Weekly recordings of transfer payments	<ul style="list-style-type: none"> ▶ Reasons for receiving transfer payment (unemployed, sick leave, part-time benefit, disability pension, or retirement pension) ▶ Dates for starting and ending transfer payment 	1 September 2007–31 December 2027
Municipality-based electronic care provision record, health database, 2012	Health services provided by the municipalities to citizens	<ul style="list-style-type: none"> ▶ Type of service (assistance for home cleaning, personal care, home visits by a community nurse, or rehabilitation) ▶ Subtype of service (eg, community nurses can inject medicine, treat wounds, or measure vital parameters) ▶ Location of service provided (eg, citizen's own home or nursing home) ▶ Dates for starting and ending the service ▶ Total amount of time assigned to the service 	1 September 2012–31 December 2027
Danish National Health Service Register, ^{23 36} administrative registry, 1990	Contacts with healthcare professionals	<ul style="list-style-type: none"> ▶ Service provider (eg, GP, physiotherapist, dentist) ▶ Type of consultation (ordinary consultations, home visits, telephone consultations, or electronic consultations via email or a secure website) ▶ Service provided (eg, paraclinical examinations, vaccination, pregnancy) ▶ Laboratory tests performed ▶ Amount of reimbursement ▶ Date of the service ▶ Dates for starting and ending treatment 	1 September 2007–31 December 2027
Danish National Database of Reimbursed Prescriptions, ^{24 34} administrative database, 2004	Filled reimbursable prescriptions from community pharmacies	<ul style="list-style-type: none"> ▶ Name of prescribed drug ▶ Type of drug according to the Anatomical Therapeutic Chemical classification system ▶ No of pills ▶ Dose ▶ No of defined daily doses ▶ Date of redemption 	1 September 2007–31 December 2027
Prehospital electronic record, ²⁵ health database, 2012	Patient records from emergency medical services	<ul style="list-style-type: none"> ▶ Type of transport (ambulance, medical car or helicopter) ▶ Urgency level ▶ Distances ▶ Addresses ▶ Detailed patient journal included from 2017: Information on treatments, medications, and journal notes as free text ▶ Date and time stamps for take offs and arrivals 	1 September 2012–31 December 2027
Danish National Patient Registry, ^{26 37} administrative registry, 1977	Hospital contacts	<ul style="list-style-type: none"> ▶ Type of contact (inpatient or outpatient) ▶ Acute versus scheduled ▶ Hospital and department code ▶ Diagnoses, surgical procedures and examinations according to the International Classification of Diseases ▶ Primary diagnosis and secondary diagnoses in relation to the contact ▶ Course of admission (since 2019) ▶ Costs associated with the hospital contacts, treatments, and procedures ▶ Dates of admission and discharge for inpatients ▶ Date of contact for outpatients 	1 September 2002–31 December 2027

Continued

Table 1 Continued

Name and type of data source and year of initiation	Description of data source	Main variables	Period of data inclusion in the CROSS-TRACKS cohort
Electronic health record, health database, 2012	Secondary data source for the Danish National Patient Registry	<ul style="list-style-type: none"> ▶ Diagnoses, treatments, and examinations ▶ Structured registrations of healthcare content ▶ Triage ▶ Microbiology ▶ Standardised registrations on patient's pulse, blood pressure, respiration frequency etc. used for early detection of critical illness ▶ Registrations of patients' lifestyle factors regarding diet, smoking, alcohol and physical activity ▶ Recordings of patient's height and weight used for calculating body mass index. See online supplemental material 1 for details on data cleaning. ▶ Recordings of patient's blood pressure. See online supplemental material 1 for details on data cleaning. ▶ In-hospital medication: Doctor's orderings and nurses' dispensing's ▶ Meta data on updates of patient's electronic medication records shared by all Danish health professionals ▶ Journal notes as free text ▶ Date and time stamps of registrations 	1 September 2012–31 December 2027
Clinical laboratory information system, ²⁸ health database, 2000	Laboratory test results from clinical laboratories	<ul style="list-style-type: none"> ▶ Type of biological material ▶ Identification of health professional or hospital department requesting the analysis ▶ NPU codes for types of tests requested (a blood specimen can be analysed for several different contents) ▶ Test results and units ▶ Date and time of sample and test results 	1 September 2012–31 December 2027

CPR, civil personal register; GP, general practitioner; NPU, nomenclature, properties and units.

a registered partnership was 44%, and 44% of the citizens aged 18 years and above were living alone on cohort entry date.

During the inclusion period from 1 September 2012 through 2018, 35% of the total population received some kind of transfer payment. Sick leave was the predominant reason with 10%, which was followed by unemployment among 9% of the population.

A total of 21% had a CCI score of 1 or above at the end of the inclusion period. For the part of the population (66%) with a hospital contact in the period from 1 September 2012 through 2018, we used registrations in the EHR to obtain the clinical characteristics. Early detection of critical illness was registered in the EHR among 43% of the population with at least one hospital contact. Registrations of blood pressure were used to identify patients with at least one registration of high blood pressure (49%). Smoking status was recorded in 48% of individuals with at least one hospital contact, and 53% of these reported any smoking. Alcohol intake was registered in 40% with at least one hospital contact, and 30% of these had at least one incidence of intake above the recommendations of the health authorities, which is up to 7 drinks per week for females and 14 drinks per

week for males.²⁹ Of the 90 385 patients with information on BMI, 50 222 (56%) were overweight (BMI ≥ 25 kg/m²).

Healthcare utilisation

Almost everyone in the population received at least one service provided from primary care during the inclusion period. Daytime GP services were used by 95% of the population, dental services by 77% and psychologist services by 8% during the inclusion period. Municipality-based care was provided to 13% of the citizens receiving rehabilitation assistance (8%), and nursing care (8%) was the most frequent service.

Antibiotics was the most frequently used type of prescription medication; 57% of the population redeemed at least one antibiotics prescription during the inclusion period. Non-steroidal anti-inflammatory (NSAID) prescriptions were redeemed by 37%, and blood pressure lowering medication was used by 24% of the population.

A total of 42 827 patient transportations were made by the prehospital in the period from 2017 to 2018; 26% were acute, 23% were urgent, and 49% had unknown urgency level. The transports concerned 18 671 unique individuals, and 7786 individuals had more than one transport. Overall 66% of the population had at least one

Table 2 Sociodemographic characteristics, clinical characteristics and healthcare utilisation among citizens in the four included Danish municipalities (Hedensted, Horsens, Odder and Skanderborg) in 2012–2018

	N (%)
Sociodemographic characteristics	
Age at cohort entry date (1 September 2012)	
Median age at cohort entry date, years (IQR)	41 (25–58)
<18*	24 235 (11)
18–39	80 434 (36)
40–64	80 288 (36)
65–79	28 196 (13)
80+	8 130 (3.7)
Gender	
Female	109 267 (49)
Male	112 016 (51)
Municipality (on 1 September 2012)	
Hedensted	39 981 (18)
Horsens	78 758 (36)
Odder	19 493 (8.8)
Skanderborg	49 160 (22)
Other (individuals moving to the four municipalities after 1 September 2012)	33 891 (15)
Individuals moving away from the municipalities	38 967 (18)
Marital status	
Married or registered partnership	97 216 (44)
Divorced or dissolved partnership	17 859 (8.1)
Widowed or longest living in a registered partnership	11 077 (5.0)
Not married	77 815 (35)
Unknown	17 316 (7.8)
Living alone on cohort entry date†	72 967 (44)
Transfer payments	
Any kind of transfer payment	77 410 (35)
Unemployment	19 849 (9.0)
Sick leave	21 873 (9.9)
State education grant	13 021 (5.9)
Maternity/paternity leave	8 356 (3.8)
Retirement pension	8 266 (3.7)
Disability pension	1 047 (0.5)
Social security benefits	6 996 (3.2)
Deaths during follow-up	11 470 (5.2)
Clinical characteristics	
Charlson Comorbidity Index score at the end of the inclusion period	
0 (no comorbidity)	174 159 (79)
1 (low)	21 226 (9.6)

Continued

Table 2 Continued

	N (%)
2 (medium)	13 382 (6.0)
3+ (high)	12 516 (5.7)
Citizens with at least one hospital contact (recorded in the electronic health records)	147 087 (66)
Early detection of critical illness, total score‡	63 258 (43)
Diastolic blood pressure‡	102 048 (69)
Systolic blood pressure‡	102 085 (69)
High blood pressure (at least one registration of diastolic >90 mm Hg or systolic >140 mm Hg)‡	71 029 (48)
Pulse‡	100 589 (68)
Respiratory rate‡	71 904 (49)
Oxygen saturation‡	81 096 (55)
Temperature‡	71 000 (48)
Smoking status‡	70 557 (48)
No smoking§	32 978 (47)
Any smoking§	37 579 (53)
Current smoker (at last registration)§	17 484 (25)
Occasional smoker (at last registration)§	1216 (1.7)
Previous smoker (at last registration)§	18 879 (27)
Alcohol intake‡	58 833 (40)
Within recommendations; ≤7 drinks for females, ≤14 drinks for males¶	41 320 (70)
Above recommendations; >7 drinks for females, >14 drinks for males (any time)¶	17 513 (30)
Body mass index (at least one registration)‡	90 384 (61)
<18.5 kg/m ^{2**}	3202 (3.5)
18.5–24.9 kg/m ^{2**}	36 961 (41)
25–29.9 kg/m ^{2**}	30 568 (34)
30–34.9 kg/m ^{2**}	13 068 (14)
35–39.9 kg/m ^{2**}	4451 (4.9)
≥40 kg/m ^{2**}	2134 (2.4)
Triage of patients (at least one registration)‡	43 431 (30)
Immediate resuscitation (red)††	1474 (3.4)
Very urgent (orange)††	9568 (22)
Urgent (yellow)††	17 516 (40)
Standard (green)††	14 549 (33)
Non-urgent (blue)††	324 (0.75)
Healthcare utilisation	
Any health services from the municipalities	29 158 (13)
Rehabilitation (eg, physiotherapy)	17 118 (7.7)
Practical help (eg, home cleaning)	11 692 (5.3)
Personal care (eg, weekly bath)	12 419 (5.6)
Home visits by a community nurse (eg, injection of medicine)	16 709 (7.6)
Any primary healthcare contact	212 952 (96)

Continued

Table 2 Continued

	N (%)
Daytime face-to-face contact with general practitioner	210 718 (95)
Out-of-hours face-to-face contact with general practitioner	82 684 (37)
Blood tests at general practitioner	157 689 (71)
Haemoglobin test at general practitioner	106 915 (48)
Spirometer test at general practitioner	36 164 (16)
Electrocardiograph at general practitioner	81 034 (37)
Talk therapy at general practitioner	26 869 (12)
Urine test at general practitioner	92 254 (42)
Rapid strep test at general practitioner	46 179 (21)
C reactive protein test at general practitioner	132 728 (60)
Other service at general practitioner	208 597 (94)
Chiropractor	46 345 (21)
Dentist	171 333 (77)
Physiotherapist	66 788 (30)
Podiatrist	7 170 (3.2)
Psychologist	17 527 (7.9)
Prescription medication	
At least one prescription of antibiotics	126 280 (57)
At least one prescription of antidiabetics	12 577 (5.7)
At least one prescription of aspirins	21 613 (9.8)
At least one prescription of blood pressure lowering medication	53 127 (24)
At least one prescription of statins	33 837 (15)
At least one prescription of proton pump inhibitors	47 845 (22)
At least one prescription of systemic glucocorticoids	25 654 (12)
At least one prescription of inhaled corticosteroid therapy	30 999 (14)
At least one prescription of NSAIDs	80 944 (37)
At least one prescription of opioids	34 893 (16)
At least one prescription of antidepressants	30 491 (14)
At least one prescription of antipsychotics	9 767 (4.4)
Urgency level among transports in 2017–2018, total no	42 827
Acute (A)‡‡	11 181 (26)
Urgent (B)‡‡	9 637 (23)
Scheduled (C)‡‡	865 (2.0)
Supine transport (D)‡‡	23 (0.1)
Other service (E)‡‡	72 (0.2)
Urgency level unknown‡‡	21 049(49)
Hospital contacts	
At least one hospital contact	147 087 (66)

Continued

Table 2 Continued

	N (%)
At least one inpatient hospital contact	73 791 (33)
At least one inpatient hospital contact with acute admission	62 729 (28)
At least one outpatient hospital contact	134 330 (61)
At least one emergency room visit	59 382 (27)
Emergency call to the prehospital resulting in assistance by medical car	5624 (2.5)
Emergency call to the prehospital resulting in assistance by helicopter	110 (0.05)
Emergency call to the prehospital resulting in no transportation	339 (0.15)
Potentially preventable admissions among individuals aged 65+ years	8191(23)
In-hospital medication ordering	2 778 432
In-hospital medication dispensing	12 240 606
Biological samples	4 562 264
Laboratory tests in clinical laboratories	52 607 667

Data are given as number (percentage of total population) or (percentage of subpopulation) during the inclusion period (1 September 2012 to 31 December 2018), unless otherwise specified.

*Included from their 18th birthday.

†Among 166 970 individuals living in the municipalities aged 18 years and above.

‡Among 147 087 individuals with at least one hospital contact.

§Among 70 557 individuals with at least one registration of smoking status.

¶Among 58 833 individuals with at least one registration of alcohol intake.

**Last registration among 90 385 individuals with at least one registration of body mass index.

††Last registration among 43 431 individuals with at least one registration of triage.

‡‡Among 42 827 transports in 2017–2018.

NSAID, non-steroidal anti-inflammatory.

hospital contact during the inclusion period, 33% had an inpatient contact, 61% had an outpatient visit, and 27% had an emergency room visit.

In the population of individuals aged 65+ years, 8191 (23%) had at least one potentially preventable hospital admission during the inclusion period; 5941 (73%) of these had more than one potentially preventable hospitalisation.

Almost three million medications were ordered, and about 12 million medications were dispensed in the hospitals. Overall, 4.5 million biological samples were drawn, and 52 million laboratory tests were performed on these samples.

FINDINGS TO DATE

The CROSS-TRACKS cohort was established to gain greater research-based knowledge on the causes of potentially preventable (re)admissions by tracking patient

pathways across healthcare sectors. The new knowledge can be used to strengthen the collaboration across sectors and to target joint efforts.

The cohort is currently being used for several ongoing health research projects. These include a prediction model for potentially preventable hospital admissions, a clinical decision support system based on artificial intelligence, prevention of medication errors in the transition between sectors, and health behaviour and sociodemographic characteristics of men and women in fertility treatment. Another study has applied machine learning methods for early detection of sepsis and has identified potential for initiating interventions earlier.³⁰ In continuation of this study, the authors used explainable artificial intelligence to develop an early-warning score system for detection of acute critical illness.³¹ This study adds transparency in artificial intelligence by explaining which relevant EHR data predicts critical illness.

STRENGTHS AND LIMITATIONS

CROSS-TRACKS is the first cohort to provide readily available data from primary and secondary care for research projects: the data sources have already been linked, and patient pathways have been identified. A major strength of the cohort is the completeness and the high quality of the available data, which is obtained through the prospective collection of population-based data. In contrast to existing cohorts based on administrative registry data,¹⁶ the CROSS-TRACKS cohort provides comprehensive data on patient pathways including sociodemographic data and on results of diagnostic tests, medical treatments, care and rehabilitation at both settings, and patients' lifestyle factors. Therefore, CROSS-TRACKS offers both a broad focus on patients pathways, but can also be used for disease-specific research which is the aim of other cohorts (eg, Danish Centre for Strategic Research in Type 2 Diabetes (DD2)³² and The Predictors of Breast Cancer Recurrence (ProBe CaRE) Premenopausal Breast Cancer Cohort Study in Denmark³³). An additional strength is that the unique Danish CPR number allows linkage across registers and complete follow-up for all individuals; this offers the possibility to monitor disease progression over time. The clinical information about the patients can be followed through the EHR when they live in the Central Denmark Region. If they move away, the DNPR can be used to follow the individual's disease development. Additionally, the 10-year look-back period and the follow-up through 2027 hold the possibility of following citizens for up to 25 years.

Given the detailed information on medication in both sectors, this cohort presents the complete history of registry-based drug use for each individual; this fosters rich opportunities for adjusting for confounders. Furthermore, the combination of psychiatric inpatient contacts, antidepressants and antipsychotics prescriptions, and talk therapy by GPs and psychologists offers potential for identifying psychiatric disease.

In addition, several validation studies have reported high validity of the Danish registry data.^{21 26 34} The cohort itself forms a basis for easy validation as the free-text registrations in the EHR are usually regarded as the gold standard to which registry information is compared.

Nevertheless, we note some limitations of the cohort. Not all data sources have yet been validated, and there are missing data on lifestyle characteristics, as they may not have been reported for all citizens in contact with a hospital. However, investigator bias is limited since much of the data is recorded by clinicians during diagnosis and treatment, and not for research purposes. The information on medication use in primary care is based on reimbursable redeemed prescriptions, whereas no information on over-the-counter medication is available. However, citizens with regular medication use have economic incentives to acquire the prescribed drugs because of the reimbursement option. Furthermore, a study on the use of aspirin and NSAIDs found that the potential for identifying medication use through prescription registries in Denmark is high.³⁵

Another limitation is the missing data on treatments by private psychologists, physiotherapists and chiropractors; these services are not covered by the healthcare system. However, the private healthcare sector is small in Denmark and is mostly based on services eligible for reimbursement by the regions, and these services are thereby included in the registries. Additionally, private hospitals report to the DNPR,¹⁶ which also contributes to maintaining the high completeness of registry data.

The municipalities use different suppliers for reporting to the ECPR. This means that it requires extensive data management to streamline the information, and this could be a potential limitation. The inclusion of ECPR data is conducted in close collaboration with the municipalities and their data managers to ensure correct interpretation and high validity of the data.

Only the catchment area for Horsens Regional hospital is included in the cohort, and this may compromise the generalisability. However, the catchment area includes both urban and rural municipalities. In addition, citizen contacts with Aarhus University Hospital, which is located in the Central Denmark Region, are also included in the cohort through the recordings in the EHR. Because of the structure of the Danish national registries and databases, the cohort can easily be extended to comprise additional municipalities and regions and ultimately all of Denmark. Starting in 2020, we will expand the cohort to include all 1.3 million residents in the Central Denmark Region. This region consists of one university hospital, one psychiatric hospital, four hospitals with 24 hours emergency department, four hospitals without 24 hours emergency department, and ten health centres and acute clinics.¹⁶

The CROSS-TRACKS cohort provides valuable new opportunities for health research across primary and secondary care in the future; this is expected to benefit both the individual citizens and society as a whole. The cohort can contribute with new knowledge on how

to organise interventions across sectors to reduce the number of potentially preventable (re)admissions.

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Ethics approval Register-based studies require no ethical approval in Denmark. The study was approved by the Danish Data Protection Agency (file numbers 2007-58-0010 and 2012-58-006) and the Danish Patient Safety Authority (file number 3-3013-1380/1, 3-3013-1380/2 and 3-3013-2741/1).

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