

Mobile X-ray outside the Hospital: a scoping review

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Mobile X-ray, target population, population health, experience of care, cost effectiveness

Abstract

Background For several years mobile X-ray equipment has been used in intensive care units, when transportation to the radiology department was inadvisable. Now, mobile X-ray examinations are also used outside hospital. The literature describes that fragile patients may benefit from mobile X-ray, but we need to know if it is an evident alternative to hospital-based examination and in what populations.

Methods We searched PubMed, Cinahl and Embase for English-, Danish-, Norwegian - and Swedish-language studies, published within the last 10 years about mobile X-ray outside the hospital. We decided that both qualitative and quantitative studies were eligible.

Result We included nine studies in this scoping review. The results were divided into four topics : 1. Target population 2. Population health 3 . Experience of care and 4. Cost effectiveness . The conclusions are unclear, as quality of the evidence is low, the study populations are small, and the descriptions of the technology are weak.

Conclusion Mobile X-ray may be used outside hospital. There seems to be potential benefits to both patients and health care staff. Based on the published studies it is not possible to conclude if mobile X-ray examination is a relevant diagnostic offer and for whom. Further studies are needed to assess the feasibility of use in fragile patients, also regarding staff, relatives and society.

Background

For several years mobile X-ray has been used in intensive care units for making diagnostic decisions (1). Still it is used, when patients are too fragile to be transported to the radiology department (2-4). In fragile patients e.g. nursing home residents, the environmental change from home to hospital for examination may result in delirium. The patients experience disease deterioration, a need for increased care and medication for several days after the admission to the hospital (4-7). In fragile patients, examination at the hospital can be a challenge due to transport to the hospital, long waiting times, and a need to be accompanied. These patients also require extra care before, during and after the examination (7). A review published in 2017 indicated that mobile X-ray for nursing home residents in the Western world are of comparable quality to X-ray examinations at the hospital and have potential benefits as mobile X-ray reduced transfers to and from hospital, increased the number of examinations carried out, and facilitated timely diagnosis and access to treatments. But they

concluded that further research was needed to evaluate potential improvements in care quality and cost-effectiveness. Furthermore, the study population only included nursing home residents (8). For reasons described above, mobile X-ray examinations are already used outside the hospital (9-11). Our aim of this scoping review was to disclose published knowledge about the use of mobile X-ray. For that reason, we asked four study questions:

Using mobile X-ray

1. *What is the target patient population?*
2. *What are the improvements of population health?*
3. *Is mobile X-ray a cost-effective intervention compared to X-ray at hospital?*

Method

A literature search and review.

Literature search

The following databases were searched: PubMed, Cinahl and Embase. The search strategy and selection of databases were developed in cooperation with a librarian, expert in health-related literature search. The search strategy was developed in PubMed and was adapted to the other databases. In table 1 the completed search strategy used is shown. The search was carried out in December 2018 and April 2019. If any new literature in the same search was published, the author received an e-mail. Supplementary search for image quality was carried out in January 2019.

The literature search identified 1.550 items. After removing duplicates, we had 1.415 records to appraise. Of these, 218 were selected for abstract screening after screening of titles. After reading the 218 abstracts, 24 full text articles were left to assess. In the final review we included 9 publications that fulfilled our criteria. In figure 1 an overview of the included and excluded studies and reasons for exclusion is presented. In a supplementary search about image quality we identified 246 records, of which we ended up with 4 full text articles already found in the first literature search.

Table 1: Search strategy in PubMed

#	PubMed
Search number	
1	"Radiography" [Mesh]
2	"diagnostic" AND (x radiography* OR x ray* OR radiotherap*)
3	mobile AND ("radiography" OR x ray* OR radiotherapy*)
4	transportable AND ("radiography" OR x ray OR radiotherapy*)
5	Portable AND ("radiography" OR x ray* OR radiotherapy*)
6	"X-rays" [Mesh]
7	"Nursing Homes" [Mesh]
8	"Homes for the Aged" [Mesh]
9	"nursing" AND ("home" OR "homes" OR facilit*)
10	"home for the aged" OR "home for the elderly" OR "homes for the aged" OR "homes for the elderly" ((intermediate or "long-term") AND care facility*)
11	"hospital at home"
12	"Mobile Health Units"[Mesh]
13	7 OR 8 OR 9 OR 10 OR 11 OR 12 OR 13
14	"Diagnostic Imaging" [Mesh:NoExp]
15	15 OR 1 OR 2 OR 3 OR 4 OR 5 OR 6
16	16 AND 14
17	17 NOT "mammography"
18	18 Filters: English; Danish, Norwegian; Swedish
19	

* meaning that the database searched for all words with different grammars.

Selection of records and methodological quality appraisal

The records were archived and assessed using the computer program 'Covidence'. In Covidence when screening the literature, in the selection you choose between 'yes', 'no' and 'maybe'. All literature selected as 'yes' and 'maybe' was double-checked by Co-author CPN.

Data extraction and synthesis:

To extract data from the selected articles, we were inspired by Peters to use a structured summary table (12).

Inclusion criteria

Study design: Randomized controlled trials, non-randomized trials, cohort studies, case-control studies, cross - sectional studies, case reports and series.

Countries: Western countries, USA and Europe. We only considered these countries as comparable concerning X-ray equipment, patient facilities, transporting, environment, nursing staff and the

purpose of using mobile X-ray.

Time period: The last 10 years. This period was chosen because X-ray equipment older than 10 years is normally not used.

Language: Abstracts and/or articles published in the English, Danish, Norwegian, and Swedish languages.

Exclusion criteria

Study design: Ideas, editorials, personal opinions, letters, study plans, newspaper articles, protocols, posters, animal research studies, reviews and metaanalyses.

Intervention: Mobile X-ray used in a hospital setting.

Results

The literature search resulted in 9 included studies (table 1). We find that there are several limitations related to the included literature, probably due to the character of the field. A few of the included studies are randomized, while the rest is non-randomized, not ranging high in the evidence hierarchy. The studies do not have many participants and some of the studies are based on opinions and predictions. Therefore, the quality and the results of the studies are limited.

Mobile X-ray was compared to hospital X-ray in all studies. The interventions were mobile X-ray (13-20) and mobile X-ray combined with hospital X-ray (21). The most common X-ray examinations were of chest, hip and pelvis, spine and abdomen, but not all studies included all the mentioned examinations. Some studies only included chest X-rays (15,17).

The literature describes several different qualitative and quantitative methods to measure outcomes such as population health, experience of care, quality and costs (13-21). The quality of the studies

differs a lot and there is no agreement on the appropriate outcome measures. The quality of the studies is low and may be biased. To define specific outcomes of mobile X-ray, a specific target population is needed.

Target patient population

The study populations in the literature were frail elderly, homeless, drug users, asylum seekers, and nursing home residents (13-21). We do not know, if the included target population in the literature benefits from mobile X-ray and therefore this target population may be too large. The problem is also, that the target population might differ in each country and therefore it may not be possible to define a specific target population for mobile X-ray in general. But this does not mean that mobile X-ray could not be used in other locations than described in the literature, e.g. at the local general practitioner (GP), in a healthcare center in order to meet the ambulant patient's needs, but also the needs of the health care staffs, crowded hospitals and general practitioners. We do not know if the locations described are the right locations. It may differ in each country.

Improving population health

Improvements of population health are measured by several different outcomes that by proxy may indicate if health status is improved. The outcomes were delirium measured by confusion assessment method, sensitivity and specificity of mobile X-ray to find tuberculosis, patient and health care satisfaction measured by qualitative interviews and questionnaires, image quality and costs (13-21). The outcomes of the studies describing improved population health give a mixed and unclear indication of what to be used as outcome measures.

The literature suggests that mobile X-ray seems to increase the certainty of presumed diagnoses so that treatment could be avoided in many cases (15-17,20). Examination using mobile X-ray could also prevent patients from being treated at the hospital. Fewer patients may need transportation to

the hospital, and probably fewer patients would become delirious (15-17,20). The literature also describes places to use mobile X-ray outside the hospital for instance in nursing homes and shelters (13-21).

For nursing home residents that may suffer from pneumonia, mobile X-ray was considered a reasonable alternative to hospital X-ray examination. Patients with chest pathology could be treated at home. This reduced the incidence of delirium (15-17,20). Also, less transfer to the hospital is a positive outcome, since transportation of patients from their homes to the hospital may worsen the condition of demented or disorientated patients.

The negative consequences of the transfer may result in residents not being examined or hospitalized. Examination in the familiar surroundings may calm down the patients, as insecurity during transportation to hospital is experienced as pain or confusion (16-18,20,21).

The included studies both use qualitative, quantitative, evidence-based outcome measures and non-evidence based methods. Proper outcome measures remain to be established.

Experience of care

The five included studies explored the quality, usefulness, knowledge, and expectations of mobile X-ray offered to nursing home residents. Patients, healthcare staff, nurses and referring doctors were asked using both qualitative and quantitative methods (15,17,19-21).

The literature found that the main part of patients and health care staff was satisfied with mobile X-ray examination and the benefits that mobile X-ray had for both patients and staff (15,17,19-21). Results showed high patient acceptance of mobile X-ray. The patients were happy not having to go away for several hours, felt safe and that it was much better than going to the hospital for

examination. No patients had a negative opinion of the procedure. Nursing home staffs pointed out beneficial factors such as the security and comfort for the patients who could remain in their usual environment, no need for transportation, and no need for staff to be absent from the nursing homes while accompanying the patient to the hospital (15,17,20).

But the question is if the quality of the studies permits making conclusions concerning experience of care. No studies measured satisfaction in a randomized controlled trial. We did not find two studies measuring experience of care using the same outcome measures in an identical population. We found, that the target population for measuring experience of care could also be other groups than the patients and health care staff in the studies. For instance GP, heads of departments, relatives or other persons involved in mobile X-ray.

The literature shows that mobile X-ray may facilitate high quality of treatment and care. At the same time it was pointed out, that the diagnostic quality of the images may be a challenge, since the health care staff may have to choose between good enough image quality with no transportation of patients and optimal image quality with transport. Also, there was no consensus of how to measure the diagnostic image quality (15-17,19,21).

When asking the referring doctors if the mobile X-ray examination had given important information to patients and their families, they replied positively (15,17,20).

The literature shows that measuring experience of care is difficult and it may be the reason why no one has documented a gold standard for doing that. We find that it is difficult because the patients are fragile and therefore, they are probably not able to share their experiences of mobile X-ray. Information from referring doctors, healthcare staff, and relatives may be biased and not representing patients' views.

Cost effectiveness

We found no study measuring cost effectiveness. To conclude if mobile X-ray is cost efficient, all possible measurable costs of both mobile X-ray and X-ray at the hospital must be compared in an economic evaluation with clear outcome measures.

The literature describes that mobile X-ray is cost effective compared to X-ray at the hospital, but this is not supported by evidence. No studies compare cost effectiveness between mobile X-ray and X-ray at the hospital. The studies investigate costs such as cost per patient, salary, capital costs of equipment and facilities, and operating costs. It is only possible to suggest that the cost is probably lower using mobile X-ray seen in a very narrow perspective not including derived costs (15,19,21).

Many patients would not have been examined, had mobile X-ray service not existed (20).

Author and year	Source origin	Aim/Purpose	Study population	Methodology	Intervention type	Setting	Organization	Design/Concept	Duration of the intervention	How outcomes are measured	Key findings	Limitations
Aldridge 2015 (13)	England.	To compare current practice for encouraging homeless people to be screened for tuberculosis using mobile X-ray.	Homeless people in 59 hostels (n=1,192)	Cluster randomized.	Mobile X-ray to homeless residents in randomized hostels.	The settings were hostels for the homeless in London.	A National Health Service, 'Find and Treat' led the mobile X-ray service.	Quantitative.	Feb. 2012 to Oct. 2013.	The number of eligible clients at a hostel venue screened for active pulmonary tuberculosis by the mobile X-ray.	Of 59 eligible hostels, 46 were randomized. The study found no evidence that volunteer peer educators increased client uptake of mobile X-ray unit screening	No individual data was collected. No power measurements since it would take a larger study population. Only chest X-rays and no skeletal

											for tuberculosis.	tal X-ray examinations since they screened for tuberculosis.
Dozet 2016 (14)	Sweden.	To determine whether examinations of patients in elderly care facilities with mobile radiography were cost effective from a societal perspective compared with hospital based radiology examinations.	Nursing home residents in two different areas (n=312).	A prospective study.	Mobile X-ray service to patients in one district and X-ray at the hospital to the patients in the other district.	Nursing homes were data from two districts was compared. Central district including 10 nursing homes where the distance from nursing homes to the nearest hospital was between 0-39 km. And North west district including 6 nursing homes where the distance from nursing	Cooperation with the hospital radiograph service.	Quantitative.	Nov. 2012 to May 2014.	Using questionnaires distributed to the nursing homes.	Mobile X-ray has significant lower costs per examination compared with hospital based radiography. Differences in health care related costs were also significant lower using mobile X-ray.	The study only measured health care related costs. There was an imbalance in number of participants from the two districts. The participation was voluntary so not all patients replied on the questionnaire. They could not ascertain whether mobile radiography increased

						home to the nearest hospital was between 0-30 km.						the use of radio graphy or not.
Eklund 2012 (15)	Sweden.	To investigate the usefulness of a mobile radio graphy service for radiological assessment of patients in nursing homes from the patient and staff perspectives.	Nursing homes patients.	Feasibility study where patients (n=123) and staff (n=123) answered questionnaires.	Mobile X-ray services for nursing home residents.	Nursing homes in 10 municipalities in the surroundings of Lund.	Part of the hospital service.	Quantitative.	Sep. 2008 to Sep. 2009	Questionnaires measuring patients and staff experience with the mobile X-ray service.	The main beneficial factors were security and comfort, acceptance from the patients, no need for transportation, no need for staff to be absent from the nursing home.	This study is conducted primarily using questionnaire. First the authors asked nurses responsible in 10 municipalities about their opinions about the need of mobile X-ray. Their responses were used to develop a questionnaire to all the nurses in nursing homes that participated in the study. Limitation

s of the study are that data before mobile X-ray are based on estimates on time from the healthcare staff, which results in recall bias and also the sense of time is individual, so this result may be biased.

Out of 123 patients 62 were able to answer the questionnaire about patient satisfaction. This means that only half of the patients partic

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Montalto 2015 (16)	Australia.	1. To describe the activity of the mobile X-ray service (MXS), its recipients and the number and type of plain X-rays performed. 2. to measure the impact of the mobile X-ray service on the emergency department attendances	The top 30 RACF users of mobile X-ray service in Melbourne (n=919).	Descriptive study, that uses before and after cohort approach.	Mobile X-ray vs. X-ray at the hospital.	The Mobile X-ray Service was offered in the northern and western regions of Melbourne to nursing home residents.	The mobile X-ray service was organized from the hospital.	Quantitative.	1 July 2012 to 30 June 2013.	All plain X-rays requested by and/or conducted on residents from the 30 RACF.	The MXS delivered 1,532 services attendances to 109 different RACFs. Most patients were bed or wheelchair bound followed by those who needed assistance to ambulant. There were an 11,5% reduction in Emergency Department	The study was conducted during implementation of MXS. Based on a single service on a single hospital. The study is not randomized. The study population was chosen from the authors based on their use of MXS. There

		es by residents of residents of the residential aged care facilities (RACF) who require plain X-ray services.									nt representation the year where mobile X-ray was offered.	was no patient payment as in other services. Some of the authors were involved in the service delivery.
Ricauda 2011 (17)	Italy	To explore the quality of imaging and clinical outcomes using mobile X-ray.	Frail elderly patients already attending Hospital at Home Service. Eligible participants were immobilized or chair bound, acutely ill, at intermediate or high risk of delirium and in need of a radiological examination of	Randomized controlled trial as a part of a pilot study	Mobile X-ray vs. X-ray at the hospital.	At the patients own home.	No organization is described, but probably mobile X-ray is in corporation with the hospital.	Quantitative.	June 2008 to June 2009	Confusion Assessment Method (score). Satisfaction. Image quality.	After X-ray examination in an acute confusion state requiring treatment occurred in 17 % of the patients in the hospital group vs. 0 % in the mobile X-ray group. 94 % of patients examined with mobile X-ray were satisfied. No differences in	The study is a pilot study and the purpose of the study was to explore the quality of imaging and clinical outcomes. There was no sample size calculation and since it is a pilot study, the sample size is small. The authors have not

the chest, pelvis, hips, joints, upper or lower limbs, hands, or feet. Patients were excluded if they had delirium according to the Confusion Assessment Method or were in need of urgent examination (with in 24 hours), or needed X-ray examinations not suitable at home (n=69).

image quality.

described how, when and why they measured patient satisfaction they wrote that 'satisfaction with home radiography was very good or excellent for 94 % of patients'. The authors did not compare the result of satisfaction with for instance patients examined with X-ray at the hospital. A result is that 17 % of the patients in the hospital radiography

group required treatment due to confusion | state whereas no patient in the mobile X-ray group developed delirium. The authors do not write whether or not 17 % is high or low and what they expected. Patients who needed an urgent examination (within 24 hours) and patients needing an X-ray examination not suitable at home were excluded. The authors do

not explain why these two patient groups are excluded. This means that we do not know if how and if this affect the result . It might be the weakest patient group and the patient groups in greatest risk of developing delirium that need urgent X-ray examination.

It seems that only patients who are referred to X-ray examination of thorax is included since

the authors write that the criteria rated 'symmetrical reproduction of the thorax'. This means that all skeletal examination patients is not included and images is not evaluated.

There are several limitations of this study and therefore the results may be biased and difficult to generalize. As the authors write themselves the pilot trial suggests that 'health

												care is going home'.
Story 2012 (18)	England.	To establish the sensitivity and specificity of mobile digital CXR and to test the hypothesis that actively identified cases have reduced the odds of sputum smear positivity vs. those presenting passively to health care services from the same populations.	Homeless, drug users and asylum seekers (n=352).	Observational study.	Screening using mobile X-ray.	Homeless hostels, day centers, drug treatment services and prisons in London.	Part of the Hospital service.	Quantitative.	April 2005 to March 2010.	All individuals were included, sensitivity and specificity was calculated.	The intervention had a sensitivity of 81,1% and a specificity of 99,2%. After adjusting for confounding there was evidence that cases identified through screening were less likely to be smear-positive than passively identified cases.	Small patient group. It is not a randomized trial. Analysis is based on existing data, meaning that confounding variables was not possible. The time period when data was collected vary and may impact the result.
Thines 2010 (19)	Norway.	To explore knowledge about expectations.	Nursing home residents.	Focus group interview with an unknown.	Mobile X-ray.	The setting was in nursing home.	Mobile X-ray is organized from the hospital.	Qualitative.	2 months, intervention.	Transcription and recording interviews.	Every one thought that mobile X-ray would	The study method is a focus group interview.

		ons, meanings and opinions concerning implementing mobile X-ray at nursing homes.		own number of participants in the three groups: Nurses, health care staff and radiographers.		already included in a pilot project. No exclusions concerning size of nursing home, distance to hospital was used or number of X-ray examinations.					<p>d be a great advantage for the patients due to no transportation to the hospital.</p> <p>Implementation of mobile X-ray demand great corporation between health care staff, great communication and maybe an increased workload.</p> <p>view of three health care staff groups. Nurses, radiographers and health care helpers. The study is based on expectations and not on experiences. The interview did not include doctors and secretaries, which means that we do not get their point of view. The doctors have several parts in mobile X-ray since they are the one who refer</p>
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												<p>the patient to the examination, decides the further treatment and radiologists evaluate the images. The secretaries are the ones who might do all the administrative work concerning the examination.</p> <p>Over all the study is good planned and conducted.</p>
Vigel and 2017 (20)	Norway.	To examine the use and benefit of a mobile X-ray service that enables imaging	The study population is nursing home residents. Questionnaires on behalf of	Cohort study based on a pilot study.	Satisfaction with mobile X-ray.	42 Nursing- and assisted living homes in 10 municipalities in Norway.	Oslo University Hospital was responsible for the mobile X-ray service.	Quantitative.	March to Sep. 2015.	Questionnaires to referring doctors and follow-up doctors.	In 73% the patients would have been sent to the hospital radiology department	<p>The study form is a part of a pilot project.</p> <p>The questionnaires are only for doctors</p>

		ning at nursing homes.	the patients fulfilled by: referring doctors (n=300) and follow-up doctors (n=100).								nt if the mobile X-ray service had been available. In 20% the patients would not have been examined.	rs, so no other health care workers, patients or relatives were included in the study. The response rate is low. There are no endpoints measured. There are no data before and after implementing mobile X-ray for instance concerning hospitalization.
Kjelle 2018 (21)	Norway.	To analyze the cost of with a social perspective of X-ray examination and treat	Simulation of nursing home residents (n=1.000)	A case control study -	Two alternatives were compared, including a hospital-based service and a comb	Settings were hospital compared to nursing homes. Distance to the nearest hospi	Mobile X-ray was offered from the Department of Radiology at the hospital.	Quantitative.	Data was collected in 2015.	Costs based on the 2016 Norwegian kroner converted to the Euro.	Cost per examination at the hospital was EUR 2.790 and in combination with mobile X-	Effects of mobile X-ray service were not evaluated only costs. When real data could

		ment of nursing home residents.			ination of hospital-based and mobile radiography.	tal was between 6-53 km and the average distance was 27 km.				ray and hospital EUR 1.946 .	not be found , assumptions were made . Cost of treatment and ambulance transportation do not have high influence of the result .
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Discussion

The purpose of this review was to identify published knowledge in the Western world within the last 10 years about mobile X-ray examination outside the hospital compared to examination at the hospital. We wanted to find out if mobile X-ray is an effective alternative to X-ray at the hospital and for whom.

By conducting the literature review we hoped to find results that could show which study design and outcome measures we should use to document the effect of mobile X-ray.

It was surprising that only 9 studies could be included in the review, but when reading the studies, we found that mobile X-ray is a difficult topic with many aspects to consider when defining target population and measuring effects such as population health, experience of care and costs.

Conclusions

In conclusion, this scoping review indicates that mobile X-ray in the Western world can be used outside the hospital. There seems to be benefits for both patients and health care staff. Mobile X-ray

may increase the number of examined patients. At the same time mobile X-ray may decrease the number of patients hospitalized. Fewer hospitalizations may indicate that mobile X-ray is cost effective. In general, the literature lacks the evidence for documenting the effect of mobile X-ray.

Yet, mobile X-ray has come to stay even if we still need a clear answer of how to develop the mobile X-ray, to whom it should be offered and the cost effectiveness.

Abbreviations

General practitioner (GP) Mobile X-ray service (MXS) Residential aged care facilities (RACF)

Declarations

Ethics approval and consent to participate

The study was approved by the Ethical Committee (53 811) and Data protection system (1-16-02-124-15) in the Central Region and registered in Clinicaltrials.gov (NCT04005040).

Consent for publication

"Not applicable"

Availability of data and material

"Not applicable"

Competing interests

"The authors declare no competing interests"

Funding

"Not applicable"

Authors' contributions

MDT conducted the literature search, designed the review protocol and search strategy, conducted

the literature retrieval, reviewed all abstracts identified, read all potentially relevant articles, scored all articles included in the review, and wrote the initial draft of the paper. EMSD and CPN reviewed all abstracts identified, read all potentially relevant articles, scored all articles included in the review, and contributed to and edited the paper. FM and TEMC contributed to and edited the paper.

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Figures

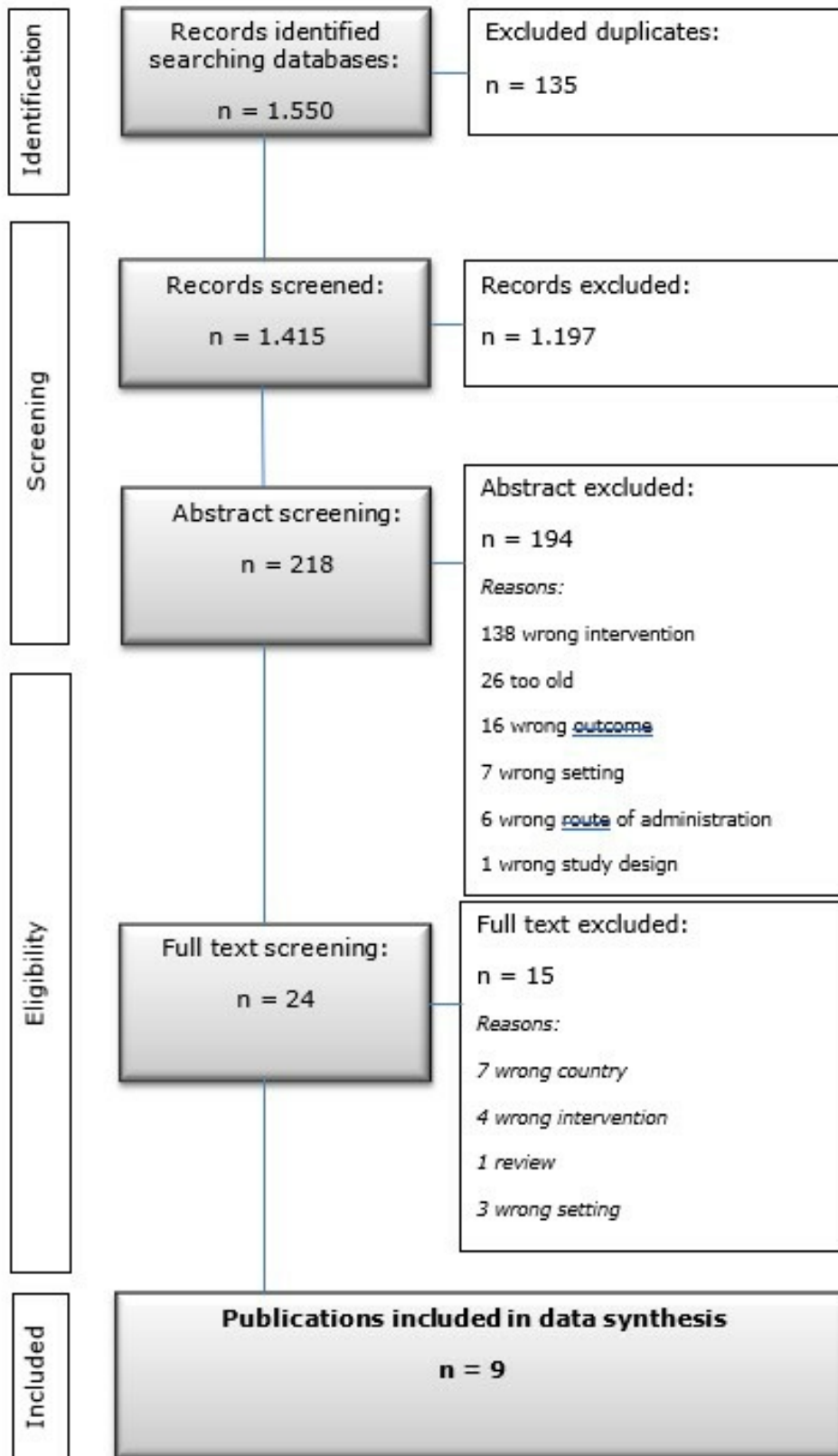


Figure 1

Flowchart of the selection process for literature search

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