Aus dem Institut für Medizinische Informatik
der Medizinischen Fakultät Charité – Universitätsmedizin Berlin

DISSERTATION

Telemedicine in Intensive Care – Examining a Use Case in light of the Findings of a Scoping Review

Telemedizin in der Intensivmedizin – die Betrachtung eines Anwendungsfalls im Rahmen der Ergebnisse eines Scoping Reviews

zur Erlangung des akademischen Grades
Doctor rerum medicinalium (Dr. rer. medic.)

vorgelegt der Medizinischen Fakultät
Charité – Universitätsmedizin Berlin

von

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Datum der Promotion: 30.06.2024

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List of abbreviations

CINAHL: Cumulative Index to Nursing and Allied Health Literature

DIVI: Deutsche Interdisziplinäre Vereinigung für Intensiv- und Notfallmedizin

ERIC: Enhanced Recovery after Intensive Care

ERIC Database: Education Resources Information Center

IEEE: Institute of Electrical and Electronics Engineers

ICU: Intensive Care Unit

LOS: Length of Stay

MEDLINE: Medical Literature Analysis and Retrieval System Online

MICU: Medical Intensive Care UnitPICO: Patient Intervention Comparison Outcome

PICS: Most Intensive Care Syndromes

PRISMA: Preferred Reporting Items for Systematic Reviews and Meta-Analyses

PSYNDEX: Database of the Leibniz-Institut for Psychologie

PsycINFO: American Psychological Association Information Database

SICU: Surgical Intensive Care Unit

Tele ICU: Telemedicine in Intensive Care Unit

Abstract

The increase in the number of critically-ill patients with complex medical history is expected to be a strain on available intensive care resources, with hospitals facing multiple challenges in maintaining an adequate level of intensive care service and quality. In this context, telemedicine interventions have been used to address some of these challenges. Such interventions rely on audio-visual systems connecting bedside staff at the ICU with a remotely-located care team.

The medical and economical results of prior analyses have been in some cases positive but overall heterogeneous. A range of contextual factors and barriers exists that influences the effectiveness of telemedical interventions. The objective of this thesis was to advance the understanding of these factors and barriers by investigating evidence about intensive care telemedicine. Building on the published results of a literature review, this synopsis brings into the focus the use case of ERIC, a tele ICU intervention implemented at Charité – Universitätsmedizin Berlin, which is discussed in light of current scientific evidence.

The thesis followed the scoping review method. First, a research protocol was published in a peer-review journal. The protocol described the literature search strategy and the steps for selecting relevant studies, extracting data from these studies, and finally charting and analyzing the extracted data. Once the protocol was published, the review was completed.

Synthesis of the data resulted in the definition of use cases for telemedicine in critical care. The ERIC intervention was classified in the use case *Improving Compliance*. Interventions in this use case aim at enhancing the adoption of best practices and improving both patient safety and quality of care. A robust body of evidence exists that intensive care telemedicine is effective at improving compliance. However, several implementation barriers were identified that may prevent telemedical interventions from fulfilling their full potential. The lack of system interoperability, which limits the ability of systems to communicate with one another, was highlighted as one of such barriers. Staff acceptance was identified as another key determinant of the success of telemedical interventions. Several strategies are available to mitigate the impact of these barriers which include targeted communication, training and definition of processes for the involved teams. Future research should help define how to effectively implement them.

Zusammenfassung

Die steigende Zahl kritisch kranker Patienten mit komplexen Krankheitsverläufen stellt eine zunehmende Belastung des Gesundheitssystems dar. Krankenhäuser stehen dabei vor der Herausforderung, die Qualität der Behandlung auf höchstem Niveau zu halten. In diesem Zusammenhang wurden vielerorts telemedizinische Intervention umgesetzt, welche mithilfe audiovisueller Systemen ärztliches und pflegerisches Personal einer Intensivstation mit einem räumlich entfernten Zentrum verbinden.

Sowohl die medizinischen als auch die ökonomischen Ergebnisse früherer Untersuchungen waren in einigen Fällen positiv, aber insgesamt heterogen, wobei eine Reihe von Faktoren und Barrieren identifziert wurden, die die Effektivität telemedizinischer Interventionen beeinflussen. Ziel dieser Studie war es, das Verständnis für diese Faktoren und Barrieren zu verbessern. Aufbauend auf den publizierten Ergebnissen einer Literaturrecherche wurde in diesem Manteltext der Anwendungsfall ERIC untersucht. ERIC stellt eine an der Charité – Universitätsmedizin Berlin implementierte telemedizinische Intervention auf einer Intensivstation dar, die im Lichte der aktuellen wissenschaftlichen Evidenz diskutiert wurde.

Die vorliegende Arbeit folgte der Scoping-Review-Methode. Zunächst wurde ein Protokoll publiziert, welches die Strategie der Literaturrecherche, die Schritte zur Auswahl relevanter Studien, die Extraktion von Daten aus diesen Studien und schließlich die Darstellung und Analyse der extrahierten Daten beschrieb. Die Synthese der Daten führte zur Definition von Anwendungsfällen für Telemedizin in der Intensivmedizin. Die ERIC-Intervention wurde in den Anwendungsfall *Improving Compliance* eingeordnet. Die Intervention in diesem Anwendungsfall zielt darauf ab, die Anwendung von Best Practices und eine Verbesserung Patientensicherheit und Behandlungsqualität zu erreichen. Es existiert umfassende Evidenz, dass Telemedizin in der Intensivmedizin die Compliance wirksam verbessert. Es wurden jedoch mehrere Implementationsbarrieren festgestellt, die der Entfaltung des vollen Potentials telemedizinischer Maßnahmen entgegen stehen. Als eines dieser Hindernisse wurde die fehlende Interoperabilität der Systeme idenfiziert, die die Fähigkeit der Systeme zur Kommunikation untereinander einschränkt. Die Akzeptanz des Personals wurde als weitere wichtige Determinante für den Erfolg

telemedizinischer Maßnahmen genannt. Verschiedene Maßnahmen, um die Auswirkungen dieser Hindernisse abzumildern, können zur Anwendung kommen, darunter gezielte Kommunikation, Schulung und Definition von Prozessen für die beteiligten Teams

Es sollte Gegenstand zukünftiger Studien sein, die Wirksamkeit dieser Maßnahmen zu untersuchen.

1. Introduction

Firstly, this section defines intensive care medicine and presents the issues facing intensive care infrastructure. It then defines the concepts of intensive care telemedicine and introduces the potential of tele ICU interventions. Finally, this section presents the research gap and explains how it will be addressed in the thesis.

1.1 Defining the issues facing intensive care medicine

i. Characterizing intensive care medicine

According to the definition by Zimmerman et al., intensive care utilizes “specialized staff and teams to provide care […] to critically ill patients with life-threatening conditions […] using protocols and principles to reverse pathophysiologic processes” [9]. Intensive care patients typically suffer from acute organ failure or are under monitoring after receiving a major procedure [1]. Intensive care is delivered in Intensive Care Units (ICU), a specialized area of the hospital. The World Federation of Societies of Intensive and Critical Care Medicine defines the ICU as “an organized system for the provision of care to critically ill patients that provides intensive and specialized medical and nursing care, an enhanced capacity for monitoring, and multiple modalities of physiologic organ support […].” [2]. There are both general ICUs (or “medical-surgical” ICUs) that deliver care for a wide range of patients and diagnoses, and specialized ICUs targeting specialty-specific diagnoses (i.e. cardiology or neurology).

ICUs can be described as resource-intensive settings. Firstly, we highlight the required staffing resources. The nursing staff is composed of nurses with qualifications in intensive care medicine. ICUs are characterized by a high ratio of nurse-to-patients, typically of 1 to 2 [3]. The physician staff is composed of intensivists, which are physicians with specialty training in the treatment of conditions seen in critically ill patients [3]. Both German and American guidelines for intensive medicine recommend the presence of physicians with specialty training in intensive care at the bedside. Additional medical staff may also include other specialties such as respiratory therapists and pharmacists [1].

Secondly, we highlight the costs of intensive care. The expense of maintaining an intensive care infrastructure is significant. According to an estimate by Vranas et al., Intensive care amounts to 15% of the overall hospital costs in the United States [4]

ii. Rising demands on intensive care infrastructure

More than 2 million patients receive intensive care treatment annually in Germany [5]. Current demographic trends in countries with high standards of living are characterized by population aging and longer life expectancy. Based on these trends, available projections indicate that demand for intensive care medicine is likely to keep increasing in the future [3]. This spending is concentrated on a small group of patients. Studies have shown that approximately half of the costs are concentrated on 10% of ICU patients [6]. Caring for cohorts of older patients with complex cases is therefore likely to represent a strain on future intensive care infrastructure [2].

While the care needs are growing, the characteristics of intensive care cases are also evolving. Because of the rising number of cases, there are now growing cohorts of patients that have survived an ICU stay [7]. These survivors are exhibiting symptoms that have been called Post Intensive Care Syndromes (PICS) [24]. According to the definition by Rousseau et al., this syndrome includes a range of “physical, mental and neurocognitive disorders that negatively affect […] the quality of life in survivors of critical illness” [8]. The growing prevalence of PICS poses an additional challenge to intensive care medicine. Prevention strategies in intensive medicine are needed to mitigate the long-term effects of intensive care treatments.

iii. Unequal distribution of intensive care resources

While the need for complex intensive care is increasing, the financial resources and workforce are limited and not equally distributed.

Firstly, intensive care infrastructure presents significant variations between countries. A comparison of the number of available intensive care beds shows that a country like Germany has three times more beds per capita than the United States [9]. A study by Wunsch et al. also showed that there is a great deal of variation in the practice and organization of intensive medicine between North America and Western Europe [9]. In the United States, the *open ICU model* of care is more prevalent. In this model, the admitting medical staff (i.e. surgeon, hospitalist) maintains responsibility for the patient, instead of being automatically transferred to a trained intensivist. According to estimates, only 10% to 20% of hospitals in the United States have a dedicated intensivist on staff [11]. Most other high-income countries such as Germany have a different intensive care model. In this model intensivists are responsible for patient care during the stay in the ICU [13]. This care model is referred to as the *closed ICU* model.

The variations in the practice of intensive medicine are also notable between large and small hospitals. Large hospitals such as tertiary hospitals in urban centers have a higher caseload and access to more extensive resources to maintain a larger intensive care infrastructure. In contrast, small hospitals, such as community or rural hospitals have limited financial and human resources to sustain the rising demands while maintaining adequate quality standards [1]. Studies have shown that disparities in the quality of care between ICUs have been significant in the United States [3]

1.2 Definition and uses of telemedicine in intensive care

i. Definition and significance of telemedicine in intensive care

Telemedicine is defined as "the use of telecommunications for medical diagnosis and patient care" [10]. A wide range of telemedical applications has been developed in many fields of medicine. In critical care medicine, telemedical systems (or tele ICU systems) have been in use since the first trials in the late 1970s [11]. The use of telemedicine in intensive care has grown continuously and become more widespread since the 1990s. Recent studies in the United States have suggested that tele ICU systems can be found in approximately 15% of intensive care beds [11–13]. In Germany, no official statistics are available on the prevalence of telemedicine in ICUs.

The term *tele ICU system* is used to refer to systems enabling the practice of Tele ICU medicine which is defined as the remote delivery of care to a critically ill patient by specialized healthcare personnel [4]. The American Telemedicine Association defines tele ICU systems as "a network of audiovisual communication and computer systems that provide the foundation for a collaborative, interprofessional care model focusing on critically-ill patients"[7]. There are two main components to this definition. On the one hand, the *technology* component defines the equipment and the system architecture. On the other hand, the *process of care* component defines how participants will use the technology. The next section presents these two components in more detail.

ii. Tele ICU system technology and care processes

This section introduces the main technical characteristics of the tele ICU systems. Detailed technical guidelines for implementing telemedical systems are provided in the guidelines for intensive care telemedicine [7,18].

Firstly, we describe the equipment that is commonly found in telemedical interventions. Tele ICU systems are composed of communication devices installed at the bedside, which include cameras, microphones, and speakers that are mounted on semiautonomous portable units [14]. A secure connection enables the transmission of audio and video between the bedside and the remote telemedical location. At the remote telemedical center, staff can access monitors equipped to enable communication with bedside staff.

Secondly, we also describe the characteristics of the tele ICU system architecture. The main model found in the literature is the centralized tele ICU model [14]. This architecture features a tele ICU center (or telemedical cockpit), equipped with communication units connecting one or multiple remote ICUs. The centralized model is illustrated in Figure 1.

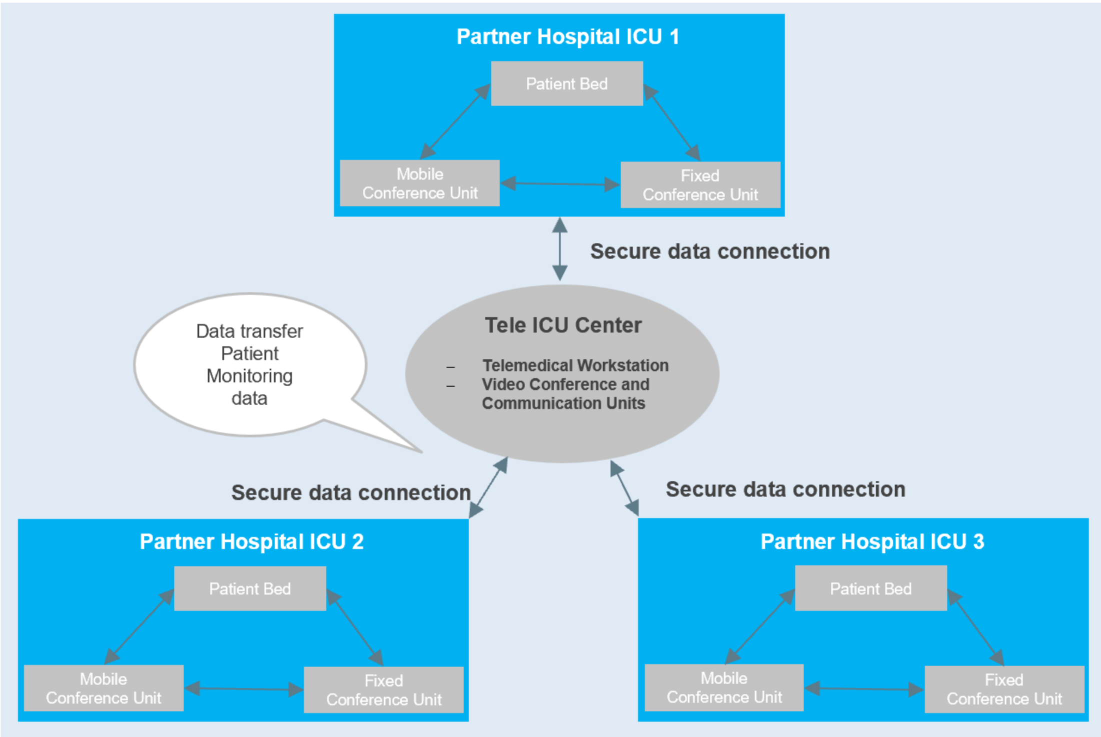


Figure 1. Centralized tele ICU system

Source: Adapted from Deisz, Telemedizin in der Intensivmedizin – Möglichkeiten und Grenzen einer Innovation, 2016 [20]

The decentralized model (or the virtual consultant model) consists of direct connections between a remote physician and the ICU. This architecture enables staff to conduct a remote consultation from another location in or outside the premises of the hospital, without a tele ICU center [7]. This model is illustrated in Figure 2.

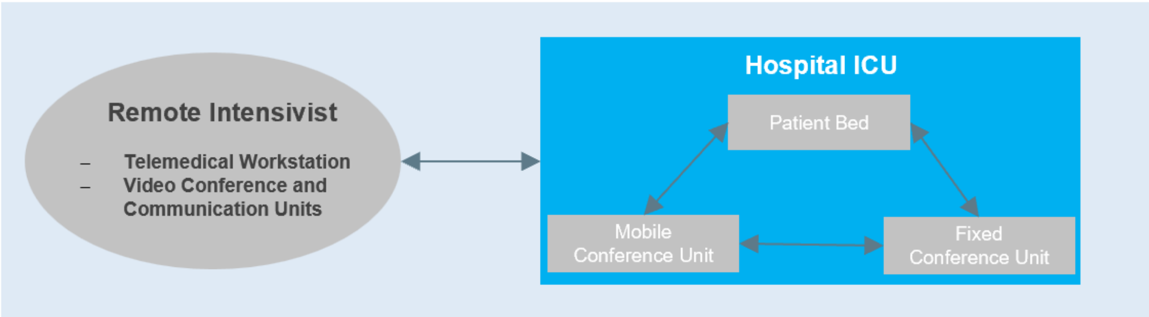


Figure 2. Decentralized tele ICU system

Source: Adapted from Rogove, How to Develop a Tele-ICU Model?, 2012 [21]

iii. The case of ERIC, a tele ICU intervention at Charité

This section highlights the technical characteristics of the intervention ERIC - Enhanced Recovery after Intensive Care. This intervention consists of telemedical rounds between on the one hand the intensivists and intensive care nurses located at an ICU center, and on the other hand, the treating physicians and nurses located at the bedside. Two-way audiovisual communication between the telemedical center and the remote ICUs is facilitated by the use of robots (“mobile cart device”). The mobile devices enable the expert team at the center to visualize the patients and the monitoring devices as well as to discuss the case during telemedical rounds [8]. These rounds include a discussion with the remote team about compliance with a set of quality indicators.
Figure 3 illustrates the semiautonomous unit used at the bedside in the ERIC intervention. This robot enables the medical personnel to see the patients and communicates with the bedside team from the remote center to conduct teleconsultations.

Figure 3. Tele ICU semiautonomous cart

Source: Adrion C et al.[15].

1.3 Addressing the research gap about telemedical intensive care interventions

i. State of research on tele ICU interventions

An extensive body of literature has been published on the topic of tele ICU interventions. In total, nine systematic reviews and nine other types of literature reviews have been published on the topic. These publications have primarily concentrated on summarizing the efficacy of ICU telemedical interventions in improving medical outcomes [1]. Results from this evidence synthesis suggest that tele ICU interventions led to a general reduction in ICU and hospital mortality [2]. Firstly, concerning the effects on mortality, earlier reviews by Young et al. found that the implemented tele ICU systems resulted in a reduction in ICU mortality without significant change in overall hospital mortality [16]. These results were confirmed by a meta-analysis from 2019 by Chen et al., in which a reduction in both ICU and hospital mortality was found [17]. Secondly, reviews synthesized results for length of stay (LOS), which was reduced at the level of the ICU according to Chen et al. [17]. No positive results were found for the overall hospital LOS. Despite some positive effects on mortality and length of stay, Venkataraman et al. have highlighted the heterogeneity of the tele ICU intervention results [18]. Although the tele ICU interventions led to positive clinical outcomes in some cases, results have also been inconclusive in several other contexts [23]. A large study by Kahn et al., based on insurance claim data in the United States, concluded that significant variations exist concerning the effect of tele ICU intervention on mortality [3]. Some tele ICU intervention studies have reported mixed or non-significant results. This lack of improvement in medical outcomes has led some authors to call for further research on the efficacy of tele ICU interventions [19].

ii. Identification of a gap in research

This section presents the research gap that was addressed in the thesis. As we established in the previous sections, existing scientific literature has primarily focused on assessing the overall efficacy of telemedical interventions. Adalovic et al. noted that existing systematic reviews and meta-analyses have not addressed the aspects of configurations of tele ICU systems in depth [24]. In a research agenda for ICU telemedicine, Kahn et al. mentioned that further research was needed to better understand the structures and processes at play in the telemedical interventions. The terms structures and processes in this context refer to the modification of the intensive care organization and the process of care that are associated with tele ICU interventions [3,4]. Kahn et al. noted that the “true value of ICU telemedicine lies not in whether the technology exists but in how it is applied […] and how it affects workflow and team integration” [20].
As noted by Lilly et al., studies about tele ICU interventions have not sufficiently focused on understanding the structural and processual factors that are associated with positive intervention results [21]. The purpose of this thesis was to improve the understanding of these structural factors. We provided an analysis of the implementation context of tele ICU interventions and of the tele ICU system characteristics to understand what influences these have had on the efficacy of tele ICU interventions.
In addition to the gap in research about implementation context, we also identified a need for more research on tele ICU from a perspective outside Northern America. As remarked by Vranas et al., there is an insufficient number of publications about the implementation of ICU telemedicine outside the United States [4]. As discussed earlier, intensive care medicine in the United States presents some specificities such as the ICU open model that are not found in other developed countries. For this reason, the thesis aimed at examining tele ICU interventions from the perspective of the Charité – Universitätsmedizin Berlin.

iii. Approach for addressing the research gap

Our approach to addressing the research gap is divided into two parts. In part one, we synthesized existing evidence on intensive care medicine by completing a scoping review. This scoping review was published in the *Journal of Medical Internet Research* (JMIR), a leading peer-review journal for digital medicine. The work on the scoping review was supported by a core research team. This core team was assembled with a range of expertise in intensive care, medical informatics, literature research, and digitization. It included a professor for medical data science (Felix Balzer, MD.), a professor for medical informatics (Martin Boeker, MD.), an anesthesiologist with intensive care specialty and lead coordinator for the ERIC Program (Björn Weiss, MD.), a researcher in anesthesiology with a specialty in digital health (Akira-Sebastian Poncette, MD.), a professor for digitalization (Daniel Fürstenau, Ph.D.) and an anesthesiologist with a specialty in intensive care (Rudolf Mörgeli M.D.) [5]. The research team provided feedback on the scoping review findings and shared insights.

In the second part, we analyzed and discussed an existing telemedical program at Charité – Universitätsmedizin Berlin, the intervention *Enhanced Recovery after Intensive Care* (ERIC). This analysis was completed in light of the scoping review from part one. This approach enabled us to compare and contrast ERIC with other interventions found in scientific literature.

2. Methods

This section explains the scoping review methods employed in this thesis. Firstly, the purpose and the benefits of using such methods are explained. Then, we see how the method was used to address the research question of the thesis. Finally, we present the extension of the scoping review methods used for the analysis of the ERIC intervention.

2.1 Rationale for the scoping review method

i. Scoping reviews as an evidence synthesis method

According to the definition by the Joanna Briggs Institute, evidence synthesis is defined as “the evaluation of research evidence and opinion on a specific topic to aid in decision making in healthcare” [22]. In light of the exponential growth in the number of scientific publications, the activity of evidence synthesis has grown in relevance [23]. Evidence synthesis has been described as an essential activity for establishing evidence-based practices in the healthcare system [24].

In health research, the activity of evidence synthesis is materialized through the publication of literature reviews. In a literature review, researchers seek to summarize published evidence on a topic according to transparent and reproducible methods. Reviews are now regularly featured in leading scientific journals. Systematic reviews have become the most prominent type of literature review [23].

Over the last decades, other literature review types have emerged and have been used as new tools for evidence synthesis. The scoping review is one of these newer types of reviews which started being formalized in the early 2000s. Scoping reviews are a type of literature research that, similarly to systematic reviews, follow a structured process. In a scoping review, researchers aim at summarizing evidence from a range of different interventions, clarifying research concepts, and identifying research gaps. According to Peters et al., scoping reviews are especially appropriate “when a body of literature has not yet been comprehensively reviewed or exhibits a large, complex, or heterogeneous nature […]” [24].

While systematic reviews concentrate on synthesizing evidence from a narrow set of similar interventions, scoping reviews take a broader approach and can include a more heterogeneous set of interventions. According to Munn et al., scoping reviews are “an

ideal tool to determine the scope […] of a body of literature on a given topic and […] an overview (broad or detailed) of its focus" [25].
There is now an extensive body of guidelines and methodological publications describing the process for writing scoping reviews. The first methodological framework for scoping review was proposed in 2005 by Arksey and O'Malley [26]. This seminal publication proposed a framework containing five essential steps constituting the scoping review approach.

ii. Addressing the research gap with the scoping review approach

We now explain why the scoping review approach was appropriate for addressing the research gap. The scoping review method allowed us to consider a wide range of different telemedical interventions. As we mentioned in the introduction, tele ICU interventions are not standardized but they can be implemented in a variety of configurations. Scoping reviews are well-suited for examining evidence from such an emerging field of research where new methods or technologies are being implemented. The scoping review method allowed us to compare and contrast different types of tele ICU implementations. The scoping review method also allowed us to consider a wide range of different evidence. As noted by Peters et al., "to support the greater breadth of scoping reviews, a variety of study designs are usually included." [24]. Thanks to this inclusive approach, we were able to analyze the context and the characteristics of a variety of implemented tele ICU systems.

iii. Important features of a scoping review

In this section, we explain what the important components of a robust scoping review are and how they were featured in the thesis.
The first important feature is for authors to demonstrate that they follow a clear and reproducible research method when writing the review. To ensure transparency of the process, research methods should be specified in detail before starting the actual work on the review. There should be a description of the process for identifying the relevant studies, selecting the studies, and collecting information from the studies. It is now an established practice for authors to write a research protocol. This protocol should describe the objectives, methods, and processes to be employed during the review.
A second important feature is for authors is to publish the research protocol at the beginning of the review. Any modification of the method needs to be documented in the

final review manuscript. It is possible to publish the protocol in an online register or a scientific journal. For this thesis, the research protocol was published in the *Journal of Medical Internet Research - Research Protocols* (JMIR Res Protocol), a sister journal of the *Journal of Medical Internet Research.* This approach afforded us the advantage of having the methods peer-reviewed at the beginning of the scoping review research.
A third important feature is for authors to use established reporting standards. The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) is a reporting guideline containing 27 items. The guideline was originally developed to assist authors of systematic reviews in communicating the rationale for the review, the methods used, and the results. First published in 2009 for reporting systematic reviews, the PRISMA guideline has grown in popularity and is now widely endorsed by the research community [27]. For our scoping review, we used the template PRISMA-ScR, an extension of the original PRISMA checklist that was designed for the reporting of scoping reviews [28].

2.2 Presentation of the scoping review method

The scoping review followed a methodological framework advanced by Arksey and O'Malley [26]. This framework is divided into five main steps which are (1): “identification of the research question”, (2) “identification of relevant studies”, (3) “selection of studies”, (4) “data charting”, and (5) “data collating” [26].

i. Step 1: Identification of the research question

In the research protocol, we formulated the main research question which is: “what are the benefits of using telemedicine technology in intensive care?”[5] This main question was followed by three sub-questions that explored the aspects of the implementation context more specifically. The first sub-question asked if some implementation contexts lead to more positive outcomes for telemedicine in intensive care? The second sub-question asked if there are ICU configurations that are more suitable for some implementation contexts? The third sub-question asked, “what types of outcomes exist for tele ICU implementation, and to what extent they have been researched in-depth?”[5] Building on the research questions, we defined three research objectives for the scoping review. The main objective was to characterize the tele ICU interventions and their implementation context.

ii. Step 2: Identification of relevant studies

Step 2 of the scoping review methodology consisted in identifying relevant studies by searching scientific literature databases. As indicated in the guideline by the Joanna Briggs Institute, the search strategy aims to be as comprehensive as possible [24]. All inclusion and exclusion criteria of the search were documented in the research protocol. The search contained sets of keywords on of intensive care and telemedicine as shown in Table 1.

Topic	**Search Keywords**
Intensive care	ICU, intensive care unit, intensive care, acute care, critical care
Telemedicine	tele ICU, remote presence, virtual ICU, ehealth, mhealth, digital health, telemedicine, telecare, telehealth, digital intervention

Table 1. Search Query Keywords

Source: Adapted from Guinemer et al. Telemedicine in Intensive Care Units: Protocol for a Scoping Review. JMIR Res Protoc 2020 [5]

The search was performed in the databases web of Science Core Collection, MEDLINE, ERIC, PsycINFO, PSYNDEX, CINAHL, and IEEE. A similar search query was used for all databases after minor syntactic adjustments. The search was done without date restrictions. Selected languages were English, French, German, and Spanish. In addition to the database searches, an online manual search was completed to find grey literature.

iii. Step 3: Selection of studies

Step 3 consisted of selecting relevant studies from the search results. After removing duplicates, a first screening round was completed. Studies were selected based on their titles, abstracts, and index terms. In a second screening round, the remaining studies were screened based on full-text analysis. The full-text screening was designed to find studies in which the PICO framework (Patient, Intervention, Comparison, Outcome) in Table 2 could be identified.

Patient	Participants provided telemedical intensive care
Intervention	Telemedical system used with at least one intensive care unit
Comparison	Comparison with the standard of care without tele ICU intervention
Outcomes	All outcomes eligible for inclusion

Table 2. PICO Criteria

Source: Adapted from Guinemer et al. Telemedicine in Intensive Care Units: Protocol for a Scoping Review. JMIR Res Protoc 2020 [5]

We included articles in which at least three of the PICO criteria were found. Additionally, studies concerning interventions in neonatal and pediatric ICUs were excluded during the full-text screening.

iv. Step 4: Data Charting

According to the scoping review guidelines by Tricco et al., data charting consists of creating “comprehensive data charting forms to extract the relevant information from the included sources of evidence”[28]. Data charting forms were developed to collect information on domains of investigation. The domains were developed and improved based on feedback from the core research team.

In total five domains were defined and for each domain, several possible categories were defined (Table 3). The first three domains described the implementation context of telemedical interventions (A to C). Domain D focused on System configuration while domain E concentrated on the implementation rationale.

Domains		Description
Implementation Context	**A. Clinical focus**	Level of intensive care specialization. Possible categories are: i. Generalist (MICU, SICU), or ii. Specialized clinical focus (i.e., sepsis, cardiology, neurocritical).
	B. ICU type	Level of intensivist involvement in the care of patients. Categories are: i. "Closed", intensivists have full responsibility for patient care, or ii. "Open", admitting medical staff (i.e. surgeon) maintains responsibility for the patient, or iii. "Open/closed", open model is in place alongside the closed model.
	C. Hospital type	Category of the hospital involved in tele ICU intervention. Categories are: i. "Tertiary" designated tertiary care institutions and teaching hospitals, or ii. "Community" for community hospitals and small medical facilities in rural or suburban settings, or iii. "Mixed" when a combination of the two first categories was found.
D. System configuration		Characteristics of the tele ICU system configuration. Categories are: i. Technical architecture (i.e., centralized vs. decentralized), ii. Staff allocation (i.e., continuous vs. scheduled), or iii. Mode of communication of the tele ICU systems (i.e., high or low data intensity).
E. Implementation rationale		Main rationale provided in the study for tele ICU intervention. Codification of the rationale and expected benefits cited for the telemedical intervention.

Table 3. Data Charting Template

Source: Adapted from Guinemer et al. Telemedicine in Intensive Care Units: Protocol for a Scoping Review. JMIR Res Protoc 2020 [5]

To test the methodology and ensure consistent results, a calibration exercise was completed with a sample of randomly selected studies. This pilot test was completed before the work on data charting for the full sample was started.

v. Step 5: Collating, summarizing and reporting results

The fifth step consisted in collating, summarizing, and reporting results from the review. During this step, the results from data charting were tabulated in a format that was consistent with the objectives of the review [28]. To provide a user-friendly overview of the findings, we presented the results in an evidence map. According to the definition by

O'Leary et al. evidence map is a tool to "produce a visual representation and critical assessment of the review landscape for a particular […] topic or question"[29]. The evidence map in this review provides an overview of the included studies, the implementation context, and the results.

2.3 Extension of the scoping review methods for the analysis of the ERIC intervention

This section presents the methods employed in the thesis for the analysis of the ERIC intervention. The purpose of extending the method was to compare and contrast the case of ERIC with other tele ICU studies found in the scoping review. We aimed at identifying which insights from the scoping review were particularly applicable to the case of ERIC.

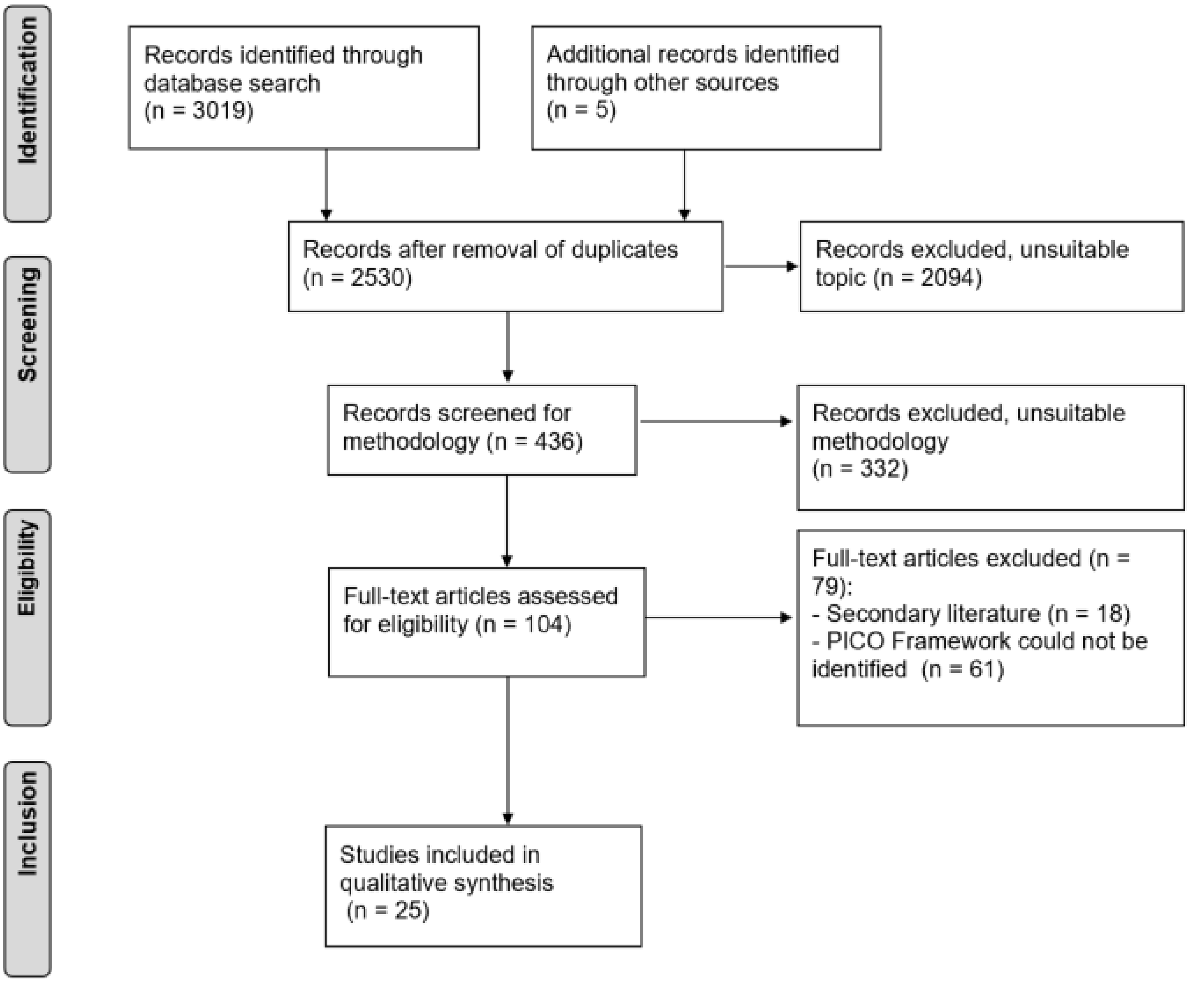
To that end, the data-charting template of the scoping review shown in Table 3 was used to describe the characteristics of ERIC and its implementation context. ERIC was mapped according to the five domains defined in the data charting template of the scoping review. A key source of information to complete this work was the protocol for a controlled trial of the ERIC intervention published by Adrion et al. [15]. The results of this extension are presented in section 3.4.

3. Results

3.1 Results from step 3 –“ Identification of relevant studies”

After screening the 3024 results, the search yielded a final sample of 25 studies. These were published between 2004 and 2019. 84% of the studies were from the United States. Other countries include Germany, India, Australia, and Saudi Arabia. Concerning the research methods, most studies used pre-post comparison designs. This method is classified as a quasi-experimental research design, in which there is no assignment of patients between the study and control group [35,36].

Figure 4. PRISMA flowchart



Source: Adapted from Guinemer et al., Telemedicine in Intensive Care Units: Scoping Review. J Med Internet Res 2021 [34]

3.2 Results from step 4 - "data charting"

This section shows results from data charting according to the five domains shown in table 3 in section 2.2.

Domains		Categories	Definition	n	% total
Implementation Context	A. Clinical focus	General	No specific clinical focus was identified (MICU, SICU)	21	84%
		Specialized	Specific clinical focus (i.e, sepsis, cardiology, neurocritical)	4	16%
			Total	**25**	
	B. ICU type	Open	Primary physician has full-time responsibility for patient care	10	40%
		Open / Closed	Features of both open and closed models	9	36%
		Closed	Intensivists available with full responsibility for patient care	6	24%
			Total	**25**	
	C. Hospital type	Tertiary	Tertiary care institutions and/or teaching hospitals	11	44%
		Mixed	Care organization spanning tertiary and community settings	4	16%
		Community	Community hospitals and/or small medical facilities	9	36%
		Not Available		1	4%
			Total	**25**	
D. System configuration		Continuous	Continuous patient critical care monitoring	5	20%
		Mixed	Continuous monitoring including scheduled rounds	9	36%
		Scheduled	Scheduled consultation at regular intervals. Virtual rounds.	9	36%
		Not Available	Insufficient information provided	2	8%
			Total	**25**	
		Centralized	Tele ICU Command Center or Hub centralizing patient care	19	76%
		Decentralized	Distributed architecture without a centralized hub	5	20%
		Not Available		1	4%
			Total	**25**	
		Direct Access	Direct staff remote access to patient data	18	72%
		Limited Access	Limited staff remote access (screen sharing) to patient data	4	16%
		Not Available		3	12%
			Total	**25**	
E. implementation rationale		Coverage	Intensivist shortage, provision of extended coverage	13	52%
		Compliance	Adherence and compliance to critical care guidelines	10	40%
		Transfer	Patients screening or triage for transfers to or from ICU	2	8%
			Total	**25**	

Table 4. Data Charting Results – Interventions and context

Source: Guinemer et al., Telemedicine in Intensive Care Units: Scoping Review. J Med Internet Res 2021 [34]

In the following, we highlight findings for each domain. Firstly, we start with the implementation context domains (A to C). For domain A, most tele ICU systems in the studies did not have a specific clinical focus. For domain B, most ICUs were organized according to the open model. (i.e. physicians keeping full responsibility for patient care). Regarding domain C, a large subset of tele ICU systems was implemented in community settings or spanning both tertiary and community hospitals.

Secondly, concerning the results for system configuration in domain D, centralized architectures were found to be the most widespread implementation setup. Concerning the staffing model, continuous care configurations (i.e. constant patient monitoring) were found in approximately half of the studies. Scheduled interventions (e.g., daily rounds) were found in a third of the studies.

Thirdly, we highlight the results for domain E about implementation rationale for which three use cases were defined. Approximately half of the studies were classified under the Use Case *1 Extending Coverage*, and 40% were classified in Use Case 2 *Improving Compliance*. The remainder of the studies was classified in Use Case 3 *Facilitating Transfer*.

3.3 Results from step five – "data collating and summarizing"

In this section, we summarized the results from step 5 of the scoping review methods. We first introduce the use cases that were identified in the data summarizing. We then introduce the evidence map, a visual representation of the scoping review results.

i. Presentation of the tele ICU use cases

The results are presented under three use cases. These use cases are intended to describe the ideal-typical situations in which tele ICU systems have been found.

The first use case *Extending Coverage* included interventions aiming at expanding the presence of intensivists in situations in which they are not (or only partially) available in the standard of care at the bedside. The analysis of the implementation context in the scoping review showed that these interventions were more prevalent in the community and mixed community / tertiary settings.

The second use case is called *Improving Compliance*. Interventions in this use case are designed to enhance the adoption of best practices, patient safety, and quality of care. Tele ICU systems in this use case were to a large extent in tertiary care institutions. The interventions were principally categorized in the cluster *Centralized Scheduled* (scheduled rounds provided from a telemedical center). A few other interventions were categorized as *Decentralized Scheduled*. In these studies, a system was put in place to enable the monitoring of key intensive care indicators such as monitoring of prophylaxis for stress ulcers, ventilator-associated pneumonia, and deep-vein thrombosis.

The third use case, *Facilitating Transfer*, included telemedical interventions enabling the management of patients that are coming to or leaving the ICU. Telemedical systems have been used in the context of transfers to a tertiary hospital (i.e. referral) or during internal transfers within the hospital (i.e. from the emergency to the intensive care unit).

ii. Evidence map of the scoping review

This section introduces the evidence map. This map provides an overview of the use cases along with the implementation characteristics of the studies included in the scoping review. Each block of columns represents one of the five data charting domains (A to E) as well as one block with information about the study method. Each line in the evidence map represents one of the 25 studies included in the scoping review.

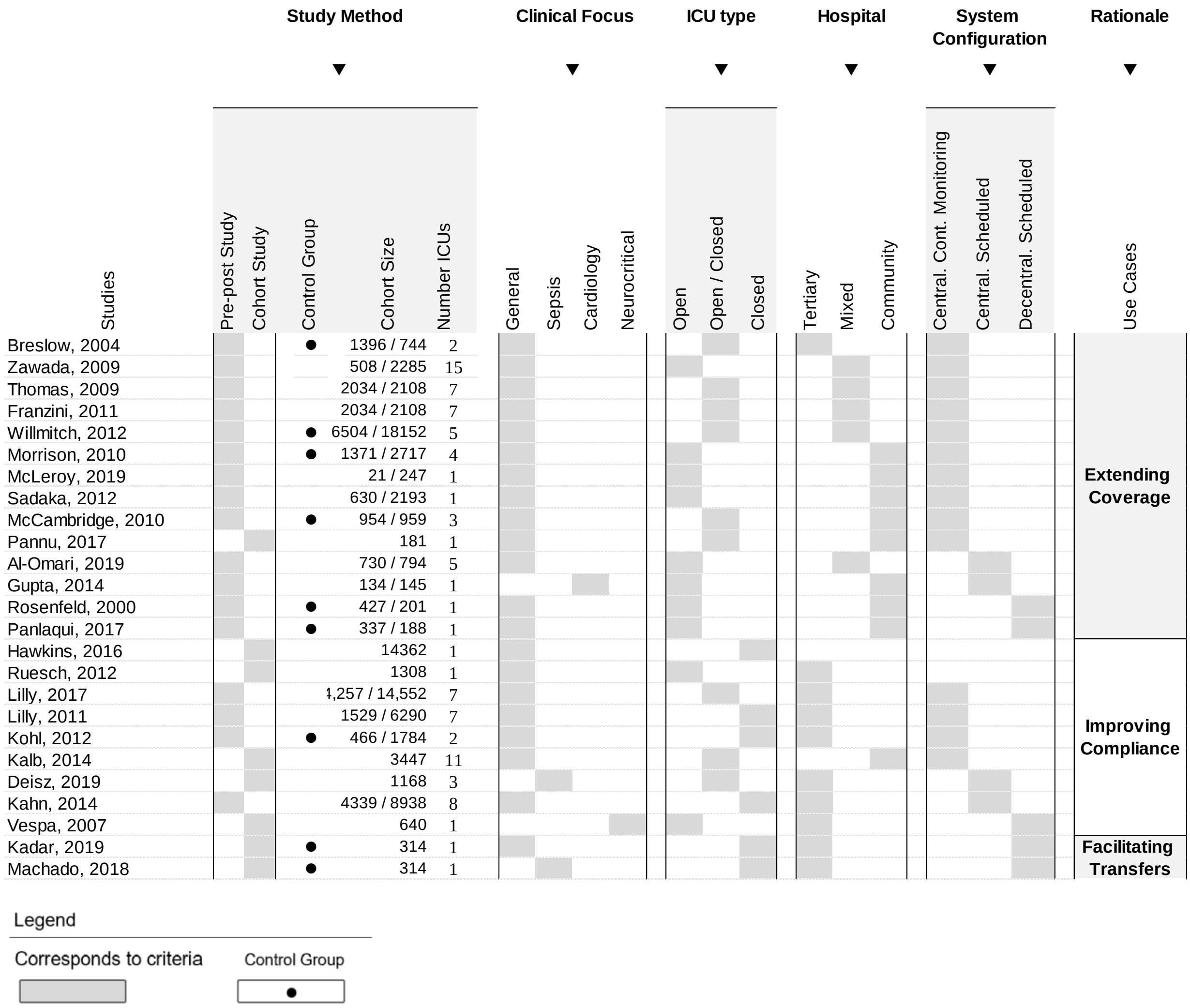


Figure 5. Evidence map of tele ICU interventions

Source: Adapted from Guinemer et al., Telemedicine in Intensive Care Units: Scoping Review. J Med Internet Res 2021 [30]

3.4 Additional results from the method extension

This section first presents the results of the data charting introduced in section 2.3 and then presents an updated version of the evidence map that includes the ERIC intervention.

i. Data charting of the ERIC intervention

Results of data charting of the intervention are presented in Table 5. Column 1 shows the five data charting template domains that were introduced in section 2.2 (step 4) of the scoping review method. Column 2 shows the categories in which ERIC was classified for each of the five domains. For example, for domain A clinical focus, ERIC was classified in the category Generalist ICU. Column 3 contains a summary of the information from the study protocol of the controlled trial for ERIC published by Adrion et al.[31].

<table>
<tr><th colspan="2">Domains</th><th>ERIC Intervention</th><th>Source Information</th></tr>
<tr><td rowspan="3">Implementation Context</td><td>A. Clinical focus</td><td>Generalist ICU</td><td>Inclusion of all patients aged 18 or above that are expected to receive treatment in a mixed, medical, or surgical ICU.</td></tr>
<tr><td>B. ICU type</td><td>Closed ICU</td><td>Intensivists at the bedside are responsible for patient care.</td></tr>
<tr><td>C. Hospital type</td><td>Mixed</td><td>Charité as a tertiary hospital is connected with hospitals in Berlin state of Brandenburg.</td></tr>
<tr><td colspan="2">D. System configuration</td><td>Centralized schedule intervention</td><td>Daily, telemedical rounds using a mobile cart are performed from a telemedical center located. In addition, a 24/7 on-call service is available. (Configuration cluster 2, see Figure 5).</td></tr>
<tr><td colspan="2">E. Implementation rationale</td><td>Improving Compliance</td><td>Intervention targeting quality improvement guided by quality indicators</td></tr>
</table>

Table 5. Data Charting Template for ERIC

Source: Analysis framework from Guinemer et al. Telemedicine in Intensive Care Units: Protocol for a Scoping Review. JMIR Res Protoc 2020 [5]*. Description of the ERIC intervention in this table extracted from the study protocol by Adrion et al.* [31]*.*

ii. Evidence map focused on the case of ERIC

Building on the previous data charting step, this section presents the results for the ERIC intervention as an extension of the scoping review evidence map. Figure 6 shows the characteristics of ERIC highlighted with diagonal stripes along with the characteristics of similar interventions in the use case *Improving Compliance*.

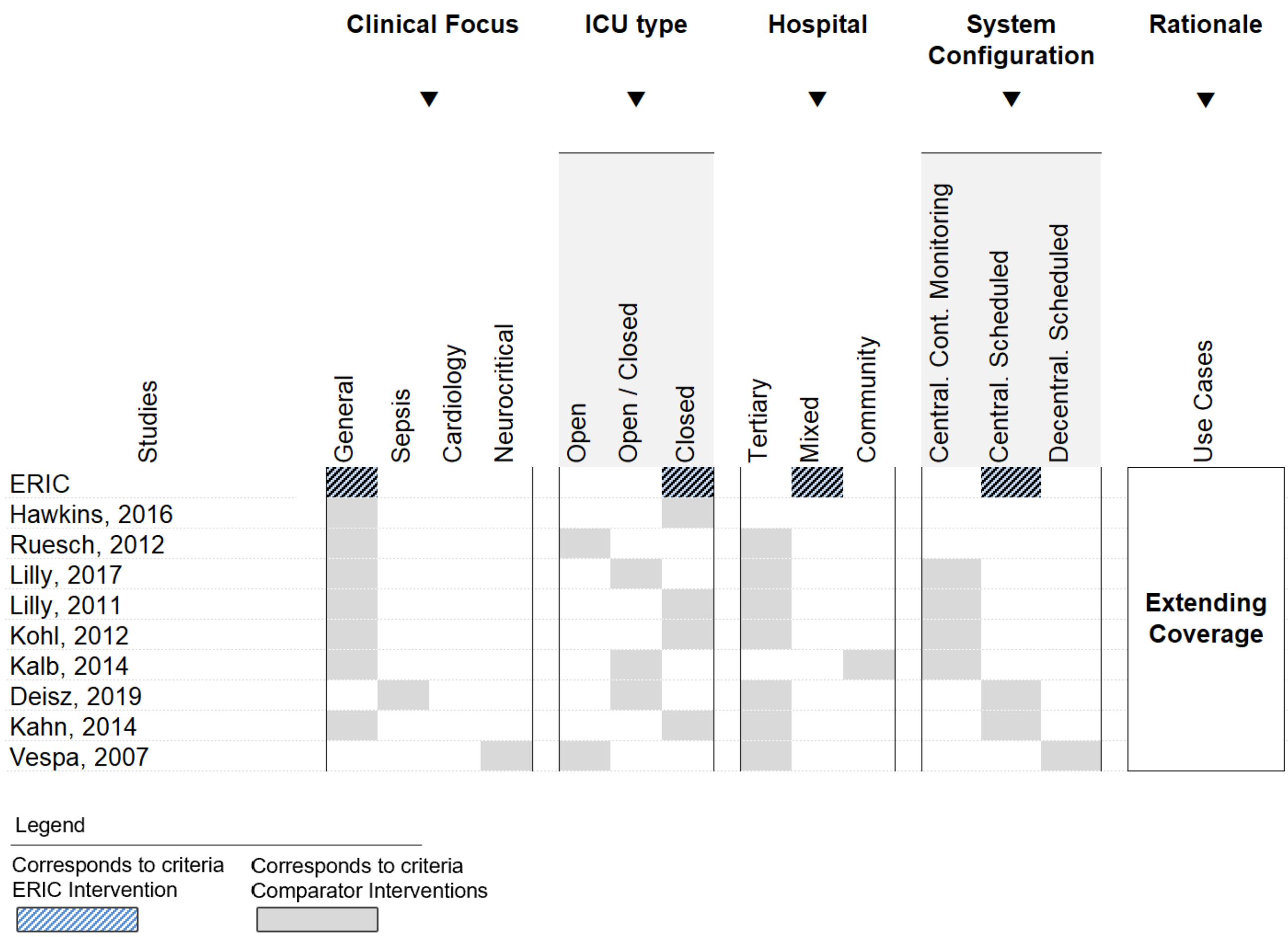


Figure 6. Characteristics of ERIC compared to interventions in the Improving Compliance cluster

Source: Adapted from Guinemer et al., Telemedicine in Intensive Care Units: Scoping Review. J Med Internet Res 2021 [30]*.*

4. Discussion

4.1 Summary of results

The literature search of the scoping review yielded 25 relevant tele ICU studies. Data charting from the studies resulted in the identification of three use cases for tele ICU interventions. The use cases were *Extending Coverage*, *Improving Compliance,* and *Facilitating Transfer*. The use cases *Extending Coverage* and *Improving Compliance* were the ones for which the most robust evidence was found. The ERIC intervention was classified in the use case *Improving Compliance*. The evidence map indicated interventions with similar characteristics as the ERIC intervention.

4.2 Potential and barriers of intensive care telemedicine for improving compliance

This section discusses the potential and limitations of implementing intensive care telemedicine for improving compliance. Firstly, to contextualize the discussion, we examined how the objectives of improving compliance were articulated in the case of ERIC. Secondly, we examined the state of evidence and highlighted the potential of telemedical interventions. Finally, we considered the limitations of intensive care telemedicine and discuss the strategies for mitigating these limitations.

i. Contextualization of the topics discussed in this section

This section provides some context and detail about the specific aspects of compliance improvement that are targeted in the ERIC intervention. As described in section 1.1, the incidence of patients having long-term symptoms and a decline in quality of life after an ICU stay has been steadily increasing. The ERIC intervention sought to address this emerging health issue through telemedicine [15]. The intervention consisted in maintaining a high level of adherence to intensive care quality indicators in the process of care. A controlled trial was launched to measure the effectiveness of the intervention in mitigating the PICS. Examining the controlled trial protocol helps us understand the clinical focus of the intervention.
In the ERIC clinical trial protocol, the DIVI Quality Indicator set, a set of widely-accepted intensive care indicators in Germany, is used as the primary intervention outcome.

These Quality Indicators are maintained by the German Interdisciplinary Society of Intensive Care Medicine or *DIVI - Deutsche Interdisziplinäre Vereinigung für Intensiv- und Notfallmedizin*. The DIVI Quality Indicators are periodically updated through a consensus-based peer-review process. Version 3 of the DIVI Quality Indicators which are summarized in Table 6 were used in the intervention. The Quality Indicators are described as process indicators, which means that they measure the adherence to a certain *process of care* (e.g. 'conducting interdisciplinary clinical visits') as opposed to an *outcome* (e.g. 'risk-adjusted patient length of stay'). According to Kumpf et al., the strength of process indicators resides in the fact that they are "easy to measure and do not require risk-adjustment for disease severity "[32]. The Quality Indicators were also designed to have "practical applicability" [32] and do not require major adaptation in the process of care.

Indicator	Definition
1	Daily multi-professional and interdisciplinary clinical visits with documentation of daily goals
2	Management of sedation, analgesia, and delirium
3	Patient-adapted ventilation
4	Early weaning from invasive ventilation
5	Monitoring of infection prevention measures
6	Measures for infection management
7	Early enteral nutrition
8	Documentation of structured patient and family communication
9	Early mobilization
10	The direction of the intensive care unit

Table 6. DIVI Quality Indicators – Version 3 (2017)

Source: Adapted from Kumpf et al., GMS German Medical Science 2020 [33]

The ERIC clinical trial protocol also mentions that adherence to quality indicators has been lacking in domains that are critical for patients suffering from PICS. Adherence to lung protection strategies is one of such domains (Indicators 3 and 4 in Table 6) These strategies aim at preventing ventilator-associated pneumonia and the atrophy of respiratory muscles due to prolonged periods of artificial ventilation. The DIVI recommends performing early weaning from invasive ventilation by proceeding with the spontaneous breathing trials [32]. In the next section, we will highlight the state of evidence about these specific strategies.

Additionally, the management of pain was highlighted in the literature as a critical domain in the mitigation of PICS. A study by Luetz et al. showed that adherence to guideline recommendations for managing pain, sedation, and delirium (Indicator 2 in Table 6) has been insufficiently used in practice [34]. The topic of pain was mentioned by Battle et al. as a major source of stress for patients and a cause of complications after the release from the ICU [35]. Quality indicators for pain management require the implementation of processes for setting sedation targets and using appropriate monitoring tools [34]. The next section will provide some insights into the potential and limitations of such processes.

ii. Discussion of evidence in the use case *Improving Compliance*

In this section, we discuss the state of evidence results for the use case *Improving Compliance* from the scoping review. We thereby highlight findings on the topics that were identified as relevant for the case of ERIC in the previous sections.
In the scoping review, we found compelling evidence that tele ICU interventions are an effective means for improving compliance. This positive effect was found across interventions with different implementation profiles. The results of the tele ICU interventions in the use case *Improving Compliance* are summarized in Figure 7. In the following paragraphs, we discuss the intervention results and then the process changes facilitating these results.

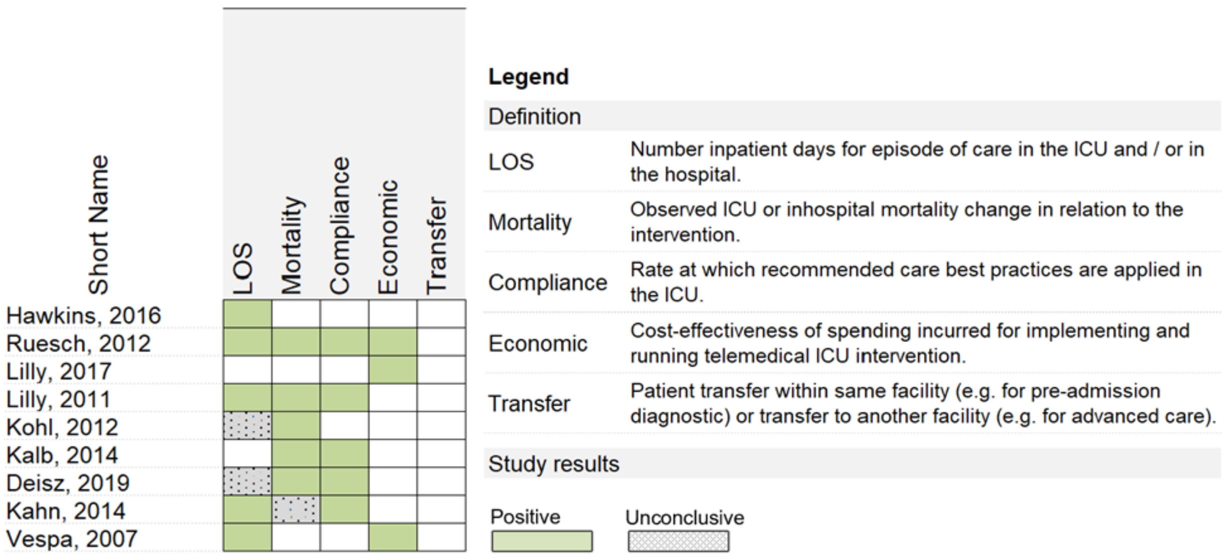


Figure 7. Results of interventions in use case Improving Compliance

Source: Adapted from Guinemer et al., Telemedicine in Intensive Care Units: Scoping Review. J Med Internet Res 2021 [30].

Discussion of results

Positive results were found in all the studies in the use case *Improving Compliance*. Positive results were also found in all the studies reporting on adherence levels to guidelines. In the study by Kahn et al., tele ICU rounds led by remote nurses at a large tertiary hospital were designed to prompt bedside staff when an omission in the process of care was noted [36]. These daily scheduled screenings by the remote nursing team were associated with shorter mechanical ventilation time and shorter LOS. Although in a different setting, similar findings were found in the study by Kalb and al [37]. In this intervention, telemedical care rounds were organized at a community hospital with a focus on lung protection strategies. This study found a higher adherence to lung protection guidelines as well as a reduction in risk-adjusted mortality. In the earlier study by Ruesch et al., a “daily management report” was used by the remote nursing staff to conduct “daily interdisciplinary rounds” with the bedside care team [38]. This study reported increased compliance with ventilator bundles and a reduction in the incidence of ventilator-associated pneumonia in ICU patients.

Discussion of Process changes

In addition to the positive results, studies in the use case *Improving Compliance* also provided insights on the process changes facilitating the tele ICU intervention results. Firstly, the organization of frequent patient rounds was found to be in most studies a key component of the intervention. The patient rounds were organized for the care teams to discuss cases. In the intervention study by Lilly et al., the early review of care plans within an hour of admission and frequent team-based review of cases was described as a key factor in the effectiveness of the intervention [39]. Different types of patient rounds were found. A model with daily scheduled patient rounds, similar to the ones in the ERIC intervention, was found in the studies by Kahn (2014) and Deisz (2019) In several interventions in the use case *Improving Compliance*, patient rounds were supplemented with the use of prompts and reminders from the remote to the bedside team in case of an omission [40].

Secondly, tele ICU interventions were described as instrumental for reinforcing the tracking of quality indicators in the ICU. Systematic tracking of indicators enables the monitoring of performance and the establishment of benchmarks. The use of benchmarks enables to implementation of targeted actions to improve compliance and continually re-assess care processes based on performance data [40]. A study by Lilly et al. about reengineering intensive care processes suggests that the use of benchmarking data was effective at reducing mortality [39].

As explained by Kalb et al., ICU interventions engender modifications of long-established care patterns in the ICU [37]. In summary, telemedicine can be used as a tool to drive change in ICU organizations to improve quality management [41].

iii. Identified barriers to intervention efficacy

In this section, we elaborate on the factors acting as barriers to the efficacy of tele ICU intervention in the domain of compliance. We highlight in particular the topic of system interoperability as a potential barrier to the success of tele ICU interventions. According to Lehne et al., interoperability is defined as "the ability of two or more systems […] to exchange information and to use the information that has been exchanged"[42]. To function properly, tele ICU systems require a constant exchange of information between the remote site and the bedside. At the minimum, this exchange consists of a two-way audio and video stream.

However, to realize the full potential of the intervention in terms of improving compliance, additional data exchanges between participating hospitals are required both in real-time and asynchronously. This data exchange may include the sharing of vital parameters and system alerts that rely on data from the patient health records. As highlighted by Bender et al., maintaining interoperability between different hospitals across organizational boundaries is a complex and time-consuming undertaking [43].

Without adequate system interoperability, the exchange of data between the tele ICU sites cannot take place automatically. This may require personnel to perform manual data entry into a specific tele ICU reporting platform since the data cannot be synchronized from the hospital health record system. Such tasks can be both time-consuming and burdensome for bedside staff and negatively impact the acceptability of the intervention. The issue of interoperability should therefore be addressed early in the planning of the intervention.

4.3 Integration of telemedical interventions in intensive care infrastructure

This section discusses the issue of the acceptance by medical staff involved in the intervention*.* Firstly, we contextualize the discussion by explaining how acceptance is relevant to the case of ERIC. Secondly, we highlight findings from the scoping review on the topic of acceptance. Finally, we outline topics for future research in the area.

i. Contextualization of the topic discussed in this section

In this section, we explain how the topic of intervention acceptance is relevant to the case of ERIC. As explained in section 1.2., ERIC can be described as an intervention with a centralized architecture. The intervention included a telemedical cockpit established between Charité – Universitätsmedizin Berlin (comprising the campus Mitte, Virchow, and Benjamin Franklin) and 11 partner ICUs located in Berlin and the surrounding state of Brandenburg. All combined, the hospitals participating in the ERIC intervention receive an average of 150 000 ICU admissions each year [8].
Since the launch of the intervention in 2018, the network of participating hospitals was extended. During the COVID-19 pandemic, additional hospitals in Berlin treating COVID-19 patients were added to the platform, within a program called SaveBerlin@COVID-19 [44]. The program was also extended internationally with hospitals in Uzbekistan and South Africa, for which Charité – Universitätsmedizin Berlin provides counseling to local ICU care teams [44].
As mentioned in section 3.4, this intervention is characterized by a mixed hospital setting, in contrast to the other interventions classified in the use case *Improving Compliance*. The mixed hospital setting is defined as an intervention between a tertiary hospital, such as Charité – Universitätsmedizin Berlin, and one or several community hospitals, such as the Krankenhaus Waldfriede in Berlin. In this setup, the Charité – Universitätsmedizin Berlin steps into the role of a center of excellence for other hospitals. In exchange, the participating hospitals benefit from the expertise and resources of the telemedical center to maintain a high level of intensive care quality locally.
Given the characteristics of the intervention and the addition of new ICUs to the telemedical platform, we found that acceptance is particularly relevant in the case of ERIC. In the next section, we highlight insights from the scoping review on that topic.

ii. The issue of intervention acceptance and mitigating strategies

An adequate level of collaboration between remote and beside teams is an essential component in achieving the potential of tele ICU interventions. As noted by Vranas et al. the quality of the collaboration between the remote and bedside teams is a factor in the effectiveness of telemedical interventions [4].To enable an adequate level of collaboration, the intervention needs to be accepted by all involved participants, and in particular by bedside staff [45].

In the scoping review, we noted that for interventions such as ERIC, the activity of the remote team can elicit ambivalent reactions from the bedside. As explained by Bender et al., care personnel can “feel threatened and scrutinized by telemedicine providers” [43]. In some cases, the bedside team can have the perception that the remote team is intruding and, to some extent, disrupting the established care routine. Such misperceptions can create a lack of trust and be a source of conflicts between teams that share responsibility for patient care. To mitigate the risks of misperception, some preventive measures can be put in place. These measures can be implemented by the team in charge of leading the tele ICU intervention. In the following paragraphs, we provide examples of such measures.

Firstly, as highlighted by Kahn et al. in an ethnographic study about the implementation of tele ICU systems, the value of the intervention needs to be perceived by the bedside personnel [46]. The benefits of the intervention should be highlighted by targeted communication and dedicated training. Beyond the communication efforts, the acceptance can also be enhanced by engaging the bedside teams in the early phases of the planning and rollout of the intervention [21]. As highlighted by Becker et al., it should be a priority to promote team buy-in and trust at the start of the intervention [12].

Secondly, the acceptance of the intervention should be reinforced by clarifying the interactions between the bedside and remote teams. As explained by Young et al., the establishment of clear rules and standards defining the role of both the remote and bedside teams is conducive to better staff acceptance of the intervention [16].

iii. Further research into intervention acceptance

In this section, we highlight the aspects of team acceptance for which further research would be necessary. First, there is a need for research to clarify how to optimally train the remote and bedside teams regarding their respective roles and responsibilities. In the ERIC intervention, an on-the-job training program was delivered using the multiplicator principle [15]. Further research in the domain would be helpful to understand the strategies and best practices for disseminating such knowledge and skills to both the remote and bedside teams.

Secondly, the impact of tele ICU intervention on medical personnel has not been investigated in depth [18]. As noted by Kopec et al., the “quality of life, retention, and longevity of bedside intensivists and critical care nurses has not been investigated” [19]. It

would be beneficial that research investigates how tele ICU intervention affects the work of the intensivists and intensive care nurses.
Thirdly, beyond the perspective of bedside and remote personnel, intervention acceptance by other participants in the intervention should also be the topic of further investigation. As we noted in the scoping review, little research was found about the acceptance of tele ICU intervention by the patients or the patients' relatives. It would be beneficial to better understand how such interventions are perceived and how these may affect the success of the intervention. For example, the topic of quality of life of patients during and after the ICU intervention has not been widely investigated [19].

4.4 Strengths and limitations of this research

This section provides an overview of the strengths and limitations of our analysis. We start by outlining the strengths of the thesis. Our scoping review is the first of its kind on the topic of tele ICU interventions. The strength of this research lies in providing a synthesis of existing evidence on tele ICU interventions with a strong focus on implementation context and system configuration. The definition of a consistent set of domains enabled us to identify three use cases from the literature. This approach allowed to provide analysis and recommendations that are specific for each use case. The evidence map provided a user-friendly document for personnel involved in the planning, implementation, and evaluation of tele ICU interventions at Charité – Universitätsmedizin Berlin and beyond. Another strength of this thesis resides in the analysis of the ERIC intervention. This analysis allowed us to discuss insights that are relevant for Charité – Universitätsmedizin Berlin.
Several limitations to this research should also be highlighted. First, several studies in the review did not use consistent reporting standards for describing the intervention and the outcomes. Some studies are lacking details on system configuration, setup, and rationale for implementation. This limited our ability to assess some aspects of the intervention, such as the autonomy of the remote team. Second, to complete the scoping review a core research group was assembled. The group provided feedback during data charting and discussion of the results. Although the insights from the team were invaluable, this qualitative approach is possibly subject to bias in the interpretation of the information from the studies. Strategies were put in place to mitigate the risk of bias. For example, the review process included steps to have the information checked by more than

one reviewer. Third, the search strategy defined in the research protocol targeted studies about tele ICU interventions for adult patients. Telemedical systems have also been implemented in other areas such as pediatric and neonatal care. A specific analysis would be required to understand interventions in these areas.

5. Conclusions

In this thesis, we investigated current evidence on telemedical interventions in intensive care using the scoping review method. We then analyzed and discussed the case of the ERIC intervention at Charité – Universitätsmedizin Berlin in light of the findings of the scoping review and current scientific literature on the topic.

Firstly, we conclude that there is robust evidence from intervention studies that intensive care telemedicine is effective at improving compliance. Implementing tele ICU systems can be instrumental in increasing adherence to intensive care guidelines. The thesis presented the mechanisms by which this positive effect can be achieved. Telemedical interventions are conducive to the development of new care processes and the establishment of a culture of compliance in the ICU. Telemedicine can be described as a valuable tool for hospitals to address the current and future challenges facing intensive care medicine.

Secondly, we observed that multiple implementation barriers exist which prevent telemedical interventions from fulfilling their full potential. Lack of system interoperability was highlighted as one of such barriers. The expansion of intensive care telemedicine, which was observed during the COVID-19 pandemic, has reinforced the need for addressing this complex and multi-faceted barrier.

Thirdly, we highlighted that staff acceptance represents an important component in the success of telemedical interventions. Intensive care telemedicine, which was described as both a technological and an organizational innovation, involves modifications of the care processes in the ICU. We discussed how these process modifications can benefit from high adherence from clinical personnel, and in particular staff at the bedside.

Based on the results of the scoping review, strategies might be proposed to foster intervention acceptance, which may include targeted communication, on-the-job training, and clarification of the roles and processes for the involved teams. We suggested areas for future research to reinforce the implementation of such strategies.

6. List included in the studies of the scoping review

Short Name	Title	Country	Ref.
Sadaka, 2012	Telemedicine intervention improves ICU outcomes	United States	[47]
Morrison, 2010	Clinical and economic outcomes of the electronic intensive care unit: results from two community hospitals	United States	[48]
McCambridge, 2010	Association of health information technology and teleintensivist coverage with decreased mortality and ventilator use in critically ill patients	United States	[49]
Willmitch, 2012	Clinical outcomes after telemedicine intensive care unit implementation	United States	[50]
Pannu, 2017	Impact of Telemedicine Monitoring of Community ICUs on Interhospital Transfers	United States	[51]
McLeroy, 2019	Implementation of Tele-Critical Care at General Leonard Wood Army Community Hospital	United States	[52]
Zawada, 2009	Impact of an intensive care unit telemedicine program on a rural health care system	United States	[53]
Thomas, 2009	Association of telemedicine for remote monitoring of intensive care patients with mortality, complications, and length of stay	United States	[54]
Franzini, 2011	Costs and cost-effectiveness of a telemedicine intensive care unit program in 6 intensive care units in a large health care system	United States	[55]
Lilly, 2017	ICU Telemedicine Program Financial Outcomes	United States	[56]
Breslow, 2004	Effect of a multiple-site intensive care unit telemedicine program on clinical and economic outcomes: an alternative paradigm for intensivist staffing	United States	[57]
Kohl, 2012	The effect of ICU telemedicine on mortality and length of stay	United States	[58]
Lilly, 2011	Hospital Mortality, Length of Stay, and Preventable Complications Among Critically Ill Patients Before and After Tele ICU Reengineering of Critical Care Processes.	United States	[59]
Kalb, 2014	A multicenter population-based effectiveness study of teleintensive care unit-directed ventilator rounds demonstrated improved adherence to a protective lung strategy, decreased ventilator duration, and decreased intensive care unit mortality	United States	[37]
Ruesch, 2012	Using nursing expertise and telemedicine to increase nursing collaboration and improve patient outcomes	United States	[38]
Hawkins, 2016	ICU Telemedicine Comanagement Methods and Length of Stay	United States	[60]
Gupta, 2014	eICU reduces mortality in STEMI patients in resource-limited areas	India	[61]
Deisz, 2019	Additional Telemedicine Rounds as a Successful Performance-Improvement Strategy for Sepsis Management: Observational Multicenter Study	Germany	[62]
Kahn, 2014	Impact of nurse-led remote screening and prompting for evidence-based practices in the ICU*	United States	[36]
Al-Omari, 2019	A Multicenter Case-Historical Control Study on Short-Term Outcomes of Tele-Intensive Care Unit	Saudi Arabia	[31]
Rosenfeld, 2000	Intensive care unit telemedicine: alternate paradigm for providing continuous intensivist care	United States	[63]
Panlaqui, 2017	Outcomes of telemedicine intervention in a regional intensive care unit: a before and after study	Australia	[64]
Vespa, 2007	Intensive care unit robotic telepresence facilitates rapid physician response to unstable patients and decreased cost in neurointensive care	United States	[65]
Kadar, 2019	Impact of Telemonitoring of Critically Ill Emergency Department Patients Awaiting ICU Transfer	United States	[66]
Machado, 2018	Impact of a telemedicine eICU cart on sepsis management in a community hospital emergency department	United States	[67]

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Statutory Declaration

"**I**, Camille Guinemer, by personally signing this document in lieu of an oath, hereby affirm that I prepared the submitted dissertation on the topic *Telemedicine in Intensive Care – Examining a Use Case in light of the Findings of a Scoping Review (Telemedizin in der Intensivmedizin – die Betrachtung eines Anwendungsfalls im Rahmen der Ergebnisse eines Scoping Reviews)*, independently and without the support of third parties, and that I used no other sources and aids than those stated.

All parts which are based on the publications or presentations of other authors, either in letter or in spirit, are specified as such in accordance with the citing guidelines. The sections on methodology (in particular regarding practical work, laboratory regulations, statistical processing) and results (in particular regarding figures, charts and tables) are exclusively my responsibility.

Furthermore, I declare that I have correctly marked all of the data, the analyses, and the conclusions generated from data obtained in collaboration with other persons, and that I have correctly marked my own contribution and the contributions of other persons (cf. declaration of contribution). I have correctly marked all texts or parts of texts that were generated in collaboration with other persons.

My contributions to any publications to this dissertation correspond to those stated in the below joint declaration made together with the supervisor. All publications created within the scope of the dissertation comply with the guidelines of the ICMJE (International Committee of Medical Journal Editors; http://www.icmje.org) on authorship. In addition, I declare that I shall comply with the regulations of Charité – Universitätsmedizin Berlin on ensuring good scientific practice.

I declare that I have not yet submitted this dissertation in identical or similar form to another Faculty.

The significance of this statutory declaration and the consequences of a false statutory declaration under criminal law (Sections 156, 161 of the German Criminal Code) are known to me."

Date Signature________________________

Declaration of your contribution to the publications

Camille Guinemer contributed the following to the below listed publications:

Publication 1: Guinemer C, Boeker M, Weiss B, Fuerstenau D, Balzer F, Poncette A-S. Telemedicine in Intensive Care Units: Protocol for a Scoping Review. JMIR Res Protoc 2020 Dec 31;9(12):e19695. [doi: 10.2196/19695]

Contribution:

- Elaboration of topic and method for the research protocol (Guinemer)
- Discussion of the method (Boeker, Weiss, Fürstenau, Balzer, Poncette)
- Pilot-testing of the method and subsequent adjustments (Guinemer, Fürstenau)
- Preparation of tables 1 and 2 and figure 1 (Guinemer)
- First draft of all paragraphs of the manuscript (Guinemer)
- Proofreading and comment of manuscript (Boeker, Weiss, Fürstenau, Balzer, Poncette)
- Final corrections of the manuscript (Guinemer)

Publication 2: Guinemer C, Boeker M, Fürstenau D, Poncette A-S, Weiss B, Mörgeli R, Balzer F. Telemedicine in Intensive Care Units: Scoping Review. J Med Internet Res 2021 Nov 3;23(11):e32264. [doi: 10.2196/32264] 31;9(12):e19695. [doi: 10.2196/19695]

Contribution:

- Database search, screening of results and final selection of literature (Guinemer)
- Preparation of textbox 1 and 2, table 1 and 2 and figures 1 to 3 (Guinemer)
- Discussion of the method and results (Boeker, Weiss, Fürstenau, Balzer, Poncette)
- First draft of all paragraphs of manuscript (Guinemer)
- Proofreading and comment of manuscript (Boeker, Weiss, Fürstenau, Balzer, Poncette, Mörgeli)
- Final corrections of the manuscript (Guinemer)

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Signature, date and stamp of first supervising university professor / lecturer

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Signature of doctoral candidate

Excerpt from Journal Summary List

Journal Data Filtered By: **Selected JCR Year: 2020** Selected Editions: SCIE,SSCI
Selected Categories: **"MEDICAL INFORMATICS"**
Selected Category Scheme: WoS
Gesamtanzahl: 30 Journale

Rank	Full Journal Title	Total Cites	Journal Impact Factor	Eigenfactor Score
1	Lancet Digital Health	1,260	24.519	0.003000
2	npj Digital Medicine	2,406	11.653	0.007450
3	JOURNAL OF BIOMEDICAL INFORMATICS	12,255	6.317	0.014690
4	IEEE Journal of Biomedical and Health Informatics	7,850	5.772	0.012840
5	COMPUTER METHODS AND PROGRAMS IN BIOMEDICINE	12,277	5.428	0.011190
5	JOURNAL OF MEDICAL INTERNET RESEARCH	26,102	5.428	0.039100
7	ARTIFICIAL INTELLIGENCE IN MEDICINE	4,245	5.326	0.004220
8	JMIR mHealth and uHealth	7,694	4.773	0.015520
9	JOURNAL OF THE AMERICAN MEDICAL INFORMATICS ASSOCIATION	12,078	4.497	0.016910
10	JOURNAL OF MEDICAL SYSTEMS	8,017	4.460	0.009500
11	Internet Interventions-The Application of Information Technology in Mental and Behavioural Health	1,658	4.333	0.003310
12	JMIR Serious Games	641	4.143	0.000970
13	INTERNATIONAL JOURNAL OF MEDICAL INFORMATICS	7,651	4.046	0.010440
14	Digital Health	676	3.495	0.001640
15	Health Information Management Journal	541	3.185	0.000540
16	STATISTICAL METHODS IN MEDICAL RESEARCH	6,654	3.021	0.015730

Printing copy(s) of the publication(s)

Publication 1: Scoping Review Protocol

JMIR Res Protoc

2020 Dec 31;9(12):e19695.

Telemedicine in Intensive Care Units: Protocol for a Scoping Review

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PMID: 33382040 PMCID: PMC7808887 DOI: 10.2196/19695

Protocol

Telemedicine in Intensive Care Units: Protocol for a Scoping Review

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Abstract

Background: Telemedicine has been deployed to address issues in intensive care delivery, as well as to improve outcome and quality of care. Implementation of this technology has been characterized by high variability. Tele-intensive care unit (ICU) interventions involve the combination of multiple technological and organizational components, as well as interconnections of key stakeholders inside the hospital organization. The extensive literature on the benefits of tele-ICUs has been characterized as heterogeneous. On one hand, positive clinical and economical outcomes have been shown in multiple studies. On the other hand, no tangible benefits could be detected in several cases. This could be due to the diverse forms of organizations and the fact that tele-ICU interventions are complex to evaluate. The implementation context of tele-ICUs has been shown to play an important role in the success of the technology. The benefits derived from tele-ICUs depend on the organization where it is deployed and how the telemedicine systems are applied. There is therefore value in analyzing the benefits of tele-ICUs in relation to the characteristics of the organization where it is deployed. To date, research on the topic has not provided a comprehensive overview of literature taking both the technology setup and implementation context into account.

Objective: We present a protocol for a scoping review of the literature on telemedicine in the ICU and its benefits in intensive care. The purpose of this review is to map out evidence about telemedicine in critical care in light of the implementation context. This review could represent a valuable contribution to support the development of tele-ICU technologies and offer perspectives on possible configurations, based on the implementation context and use case.

Methods: We have followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR) checklist and the recommendations of the Joanna Briggs Institute methodology for scoping reviews. The scoping review and subsequent systematic review will be completed by spring 2021.

Results: The preliminary search has been conducted. After removing all duplicates, we found 2530 results. The review can now be advanced to the next steps of the methodology, including literature database queries with appropriate keywords, retrieval of the results in a reference management tool, and screening of titles and abstracts.

Conclusions: The results of the search indicate that there is sufficient literature to complete the scoping review. Upon completion, the scoping review will provide a map of existing evidence on tele-ICU systems given the implementation context. Findings of this research could be used by researchers, clinicians, and implementation teams as they determine the appropriate setup of new or existing tele-ICU systems. The need for future research contributions and systematic reviews will be identified.

International Registered Report Identifier (IRRID): DERR1-10.2196/19695

(JMIR Res Protoc 2020;9(12):e19695) doi: 10.2196/19695

KEYWORDS
tele-ICU; intensive care unit; intensive care; telemedicine; critical care; implementation; scoping review

Introduction

Background

Since the first experiments in the late 1970s, telemedicine has increasingly been adopted in intensive care settings [1]. Recent figures indicate that telemedicine technologies are now in use for approximately 15% of intensive care beds in the United States [1-3]. Similar technologies have also been in use in Europe. An illustration of this trend is found at the *Charité—Universitätsmedizin Berlin*, a large university hospital in Germany, where an intensive care unit (ICU) telemedicine program focusing on quality improvement in postoperative care is being implemented [4].

An ICU is defined as a system for the provision of specialized medical and nursing care to patients located in a specific area of a hospital [5]. The term tele-ICU collectively refers to the telemedical systems that are deployed to extend or complement the capabilities of the ICU. Tele-ICU interventions are defined as the remote delivery of clinical intensive care services through conferencing and monitoring technologies [2,3,6]. Depending on the system setup, this may include audio-visual systems allowing two-way real-time communication between intensivists, bedside clinical staff, specialists, subspecialists, and patients [7]. This scoping review will focus on the implementation of these conferencing and monitoring technologies.

A range of rationales for implementing telemedicine technologies in intensive care has been suggested. Tele-ICU interventions have been described as a cost-effective response to a lack of intensive care availability. In the United States in particular, tele-ICUs have been used to address shortfalls in intensive care staffing, enabling intensivists to remotely monitor a large number of patients [6]. Additionally, tele-ICU technology allows access to populations in remote areas, thereby making specialty intensive care consultations more widely available [8]. Other applications have focused on increasing adherence to evidence-based best practices [3,9], using benchmark performance data [6]. Telemedicine in intensive care has been used as a way to improve patient safety by reducing alarm fatigue [9]. Applications in medical education, for instance, during the training of resident intensivists, has also been described [10].

Telemedicine in intensive care has been characterized by high variability in the modality and context of implementation. This is exemplified by the variety of technology setups found in the literature [6]. Tele-ICU systems may be organized according to numerous models regarding their system architecture, care intensity, and staffing pattern [7,11]. First, tele-ICU system architecture can be centralized (ie, "hub and spokes") or decentralized (ie, distributed across multiple organizations) [3]. In both configurations, systems can connect multiple institutions across organizational boundaries (ie, different institutions) and, in some cases, in wide geographic areas (from local to international). Second, tele-ICU care processes can be characterized by their care intensity [1]. Higher-intensity models feature escalation protocols for staff response combined with a proactive clinical approach. Lower-intensity setups consist of discontinuous patient coverage combined with a reactive approach to patient events [12,13]. These two tele-ICU types of engagement protocols have also been respectively labeled as "direct intervention" and "monitoring and notify" [13]. Third, staffing patterns and care team composition vary across systems. Tele-ICUs accommodate different intensivist presence times at the bedside during the day, night, or weekend, based on the needs and resources of the ICU and tele-ICU units [14]. The wider care team composition also presents some differences between tele-ICUs. It may include nurses, pharmacists, and nonclinical staff.

More generally, tele-ICUs also reflect the various forms of ICU organization found across countries or regions with different standards of intensive care. ICUs in the United States are characterized by the dominance of the "open model," with approximately 80% of ICUs staffed by nonintensivists. In contrast, in many countries, the "closed model" is predominant [10]. In this model, patients are systematically transferred to a trained intensivist. It follows that tele-ICUs have been integrated and adapted to ICUs with different models to fulfill different clinical and organizational needs.

Literature Gap

Researchers have suggested that the setup characteristics of telemedicine systems play an important role in the success of tele-ICU implementation [15]. The context of implementation has been a determinant of the form of tele-ICU organization [16]. Implementation context is defined as the structures and processes inside which a technology is deployed [17]. The organizational context is a key aspect to consider when developing new tele-ICU systems and evaluating the effectiveness of telemedicine intensive care interventions.

Extensive literature has been produced on tele-ICU interventions, including several systematic reviews [18-23]. The main focus of these reviews has been on the benefits of telemedicine implementation with regard to clinical and economical outcomes. Most studies have employed semiexperimental research designs, which include before/after comparisons with or without a control group [24]. To date, three meta-analyses have been performed for tele-ICU with hospital mortality and length of stay as outcomes [24]. Other reviews in the domain involve additional outcomes including staff satisfaction, adherence to best practices, and rate of mechanical ventilation [9].

Based on the conclusions of these reviews, benefits derived from tele-ICU implementation appear heterogeneous [15,25]. A recent systematic review by Chen et al [23] identified a positive effect of tele-ICU with a reduction in ICU and hospital mortality. However, in other tele-ICU studies, benefits derived from using telemedicine technologies in intensive care settings could not be detected [15], while other studies pointed to mixed results with a reduction in ICU mortality but no relevant impact on in-hospital mortality [18]. The variability in outcomes highlights that the benefits derived from tele-ICU interventions depend on the organization where it is deployed [11] and how the technology is applied [26]. The choice of a relevant implementation model given its context is therefore an important aspect to achieve efficacy [24]. The need for additional research about technology characteristics and implementation context has been highlighted [17]. For instance, Kahn et al noted a lack of research contributions on the factors influencing organizational and clinical effectiveness [15]. Researchers have also noted that there are currently no recommended guidelines for determining the most appropriate tele-ICU setup or composition [6].

In recent years, scoping reviews have been employed to provide an overview of the field of literature and examine emerging evidence for new types of interventions [27]. This research method has become a valuable tool for providing evidence synthesis for complex systems. A scoping review may be used to efficiently access mapping of evidence and peer-reviewed literature for a range of outcomes and thus serve as a reference for teams involved in the implementation of tele-ICUs. Scoping reviews can also help evaluate research gaps and identify the need for future systematic reviews in specific subdomains [28]. We did not find an existing scoping review on the topic after a preliminary search of online databases.

Aim

The purpose of this publication is to provide a comprehensive overview of telemedicine outcomes in relation to the ICU implementation context. We will map out evidence on outcomes of the use of telemedicine technology in intensive care and seek to offer perspectives on possible configurations of tele-ICU technologies, based on the implementation context and use case.

Methods

Research Team and Study Design

This protocol was developed using guidance from the methodological framework on scoping reviews by Arksey and O'Malley [28], and subsequent developments by the Joanna Briggs Institute [29]. This framework consists of a number of consecutive stages as follows: (1) identifying the research question, (2) identifying relevant studies, (3) selecting studies, (4) charting the data, and (5) collating, summarizing, and reporting results. We will use the Preferred Reporting Items for Systematic Reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR) checklist to report our results [30]. At present, the international Prospective Register of Systematic Reviews (PROSPERO) does not accept scoping review protocols for publication, so this protocol was not registered.

The research team consists of a doctoral researcher with a background in health economics (CG); a professor for digital health, who is a consultant anesthesiologist and a computer scientist (FB); a professor of medical informatics (MB); a consultant anesthesiologist with specialty in intensive medicine, who is a team coordinator for the intensive care telemedicine project (BW); a postdoctoral researcher in anesthesiology residency with a background in digital health (ASP); and a professor of information systems, digital transformation, and information technology infrastructure (DF).

Step 1: Identifying the Research Question

The purpose of this scoping review is to map out findings and evidence about tele-ICU in light of its implementation context. The main research question for this review is as follows: what are the benefits of using telemedicine technology in intensive care? More specifically, the following subquestions are formulated: (1) Are there implementation contexts (eg, hospital type) that are more conducive to positive outcomes of telemedicine in intensive care? (2) What tele-ICU configurations (eg, staffing) are more appropriate for certain implementation contexts? (3) What range of outcomes exist for tele-ICU implementation in the literature and to what extent have these been extensively researched?

Step 2: Identifying Relevant Studies

The databases Web of Science Core Collection, MEDLINE (via Web of Science, Clarivate Analytics), Library, Information Science & Technology Abstracts, ERIC, PsycINFO, PSYNDEX, and CINAHL (via EBSCO Host, EBSCO Information Services), as well as IEEE (via IEEE Xplore, Institute of Electrical and Electronics Engineers) have been searched for peer-reviewed literature. The search queries have been reviewed by both the information specialist and intensive care clinicians in the research team. The electronic database search will be supplemented by a manual search for grey literature. We have scanned the checklist of the Canadian Agency for Drugs and Technologies in Health to look for additional literature references.

We have followed the guidelines of the Peer Review of Electronic Search Strategies (PRESS) to formulate the queries. The exact search query used for Web of Sciences and EBSCO Host can be found in Multimedia Appendix 1. An overview of the search terms is shown in Table 1.

Table 1. Overview of the search terms.

Topic	Search keywords
Intensive care	ICU[a] Intensive care unit Intensive care Acute care Critical care
Telemedicine	Tele-ICU Remote presence Virtual ICU eHealth mHealth[b] Digital health Telemedicine Telecare Telehealth Digital intervention

[a]ICU: intensive care unit.

[b]mHealth: mobile health.

The search terms have been used in combination with the appropriate Boolean operators to formulate the search query. Search records, which include titles and abstracts, have been collated and managed using the reference management software Citavi version 6 (Swiss Academic Software). Duplicates have been identified and removed from the selection using Citavi duplicate management functionality.

A first selection of references will be performed based on screening of the titles and abstracts. Based on this selection, the full text will be retrieved and a detailed screening will be performed. The rationale for excluding studies on full-text screening will be documented and reported in the review. Full citations and a copy of the eligible studies will be retrieved and imported into Citavi.

Scoping reviews typically do not require to make a quality assessment of primary research. However, where applicable, we will complete a quality assessment of individual publications using adequate tools to appraise the quality of evidence.

Step 3: Selecting Studies

A screening guide has been developed by the reviewers to lay out the inclusion and exclusion criteria. The selection process will be first conducted by a main reviewer (CG) and then validated by at least one reviewer in the research team. Divergence in classification will be resolved through discussion based on consensus of the reviewers. To ensure consistency in the selection of sources and the review methodology, a feasibility test will be conducted among the members of the research team with a sample of 100 publications from the preliminary search.

The study selection will be divided into two steps to include both secondary and primary literature. A secondary literature screen ("level I screen") will seek to identify all secondary literature about telemedical technology used in ICUs. Publication titles and abstracts in the search results will be analyzed for inclusion. The criteria applied in the level I screen are as follows: (1) publication about telemedicine technology in intensive care, (2) research approach is a review of the primary literature, (3) no study design restriction (systematic reviews, simple reviews, and narrative reviews), (4) no country restriction, (5) language is English, German, Spanish, or French, (6) no date restriction (database will be searched from inception to present), and (7) publication in a peer-reviewed journal.

A primary literature screen ("level II screen") will then be applied to identify relevant primary literature. Eligibility criteria in the level II screen are based on the PICO framework ("Patient Problem," "Intervention," "Comparison," and "Outcome") [31] and are structured as follows: (1) participant: patients admitted and medical staff working in the ICU; (2) intervention: implementation of telemedicine technology in the ICU; (3) comparison: intensive care delivered via telemedicine compared with standard of care or ICU without telemedicine technology; (4) outcome: all outcomes are accepted for inclusion, such as clinical outcomes, economic outcomes, staff and patient satisfaction, and guideline compliance. Publications solely based on expert opinion (ie, editorials) will therefore not be included in the review. Additionally, all study designs will be considered, including both qualitative and quantitative research.

Publications about the use of telemedicine for neonatal and pediatric ICUs (NICUs and PICUs, respectively) will not be included in this scoping review. The rationale for this exclusion is that the characteristics of the patient population and organization of NICUs and PICUs are greatly different from generalist ICUs and would be better addressed in a separate review.

Step 4: Charting the Data

The purpose of step 4 is to determine the data points contained in the publications from the previous step. The data points necessary for the analysis will be tabulated in extraction sheets.

The extraction sheets will then serve as a basis of the review work.

A list of data items will be selected based on the medical and technology expertise of the research team in the domains of intensive care and telemedicine. As Munn et al [27] noted, this process of charting relevant forms is by nature iterative and is expected to evolve as literature is reviewed. Data items will be charted for this review and will enable analysis of the implementation of tele-ICUs.

The extraction process will consist of collecting and codifying information contained in the publications that describe tele-ICU systems and their implementation context. As summarized in Table 2, context is defined according to the following five topics: (1) ICU clinical focus, (2) ICU type, (3) hospital type, (4) tele-ICU system configuration, and (5) implementation rationale. Tele-ICU configuration classification is determined on the basis of the following aspects: technical architecture, staff allocation, and mode of communication within the system.

Draft data charting forms will be developed and approved by the research team after independent pilot testing using a sample of publications (ie, 10 articles). Once consistent results are achieved and forms are approved, data from all included full-text articles will be charted by one member of the research team and verified by a second member to ensure all relevant data are charted.

Table 2. Overview of data extraction topics.

Topic	Description
1. ICU[a] clinical focus	Level of specialization of the ICU. Example: Medical ICU or surgical ICU versus specialized ICU type (eg, neurological).
2. ICU type	Main organization model of the ICU. Example: Open ICU versus closed ICU.
3. Hospital type	Clinical setting where the tele-ICU is implemented. Example: Urban and tertiary hospital versus community and rural hospital.
4. Tele-ICU system configuration	Technical architecture, staff allocation, and mode of communication of the tele-ICU system. Example: A centralized system with a hub architecture providing intensive care expertise in real time versus a decentralized system with an open architecture providing scheduled care.
5. Implementation rationale	Main rationale given for implementing a tele-ICU system. Example: Extending ICU coverage versus improvement of care quality.

[a]ICU: intensive care unit.

Step 5: Collating, Summarizing, and Reporting the Results

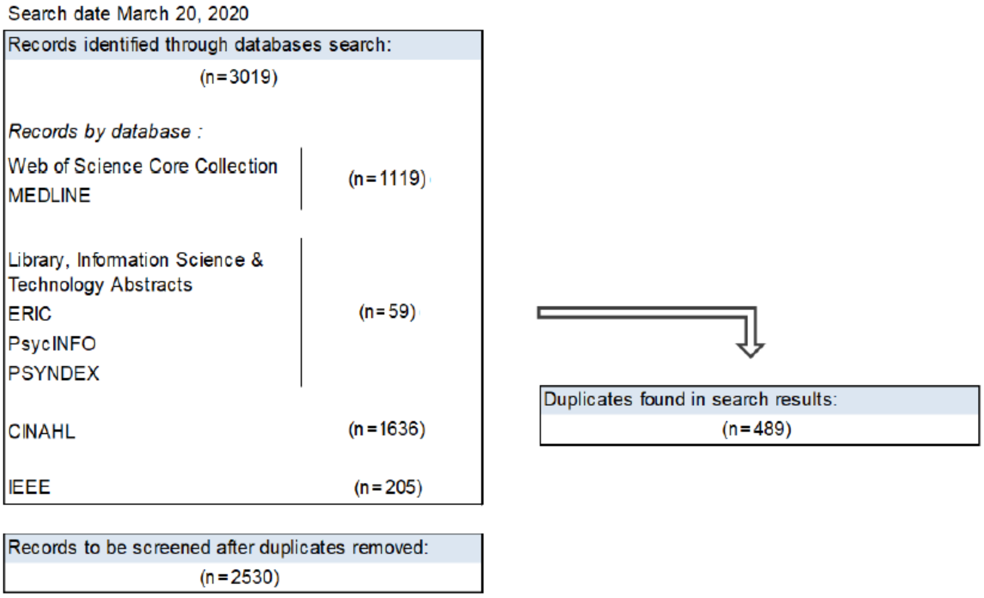
We will group the studies by the context of use and rationale for implementation. To synthesize results, we will form clusters of similar publications by classifying the data items collected. This method will allow us to analyze and compare evidence of tele-ICU implementation within each publication cluster.

We will present the results of the synthesis in the form of a series of tables, graphs, and visual representations.

Results

A preliminary research was completed to assess existing literature and ensure that no other scoping review with the same focus has been published so far. The preliminary electronic database searches were carried out in March 2020. As described in step 2 of this protocol, research results from MEDLINE, IEEE, ERIC, PsycINFO, PSYNDEX, and CINAHL were downloaded. A total of 3019 results were retrieved, of which 489 were identified as duplicates. Figure 1 shows a flow diagram with the records identified through the database preliminary search. The remaining steps (3 to 5) of the scoping review will be completed by spring 2021.

Figure 1. Literature search flow diagram.



Discussion

Preliminary Findings

The literature search yielded 2530 results after removing duplicates. The scoping review will provide a map of existing evidence on tele-ICU given the implementation context. The research findings could be used by researchers, clinicians, and implementation teams as they determine the appropriate setup for new or existing tele-ICU systems.

Limitations

Some limitations can be identified in the research approach proposed in this protocol. First, this review will seek to synthesize evidence from publications that are using heterogeneous methodologies. This will pose a limit on the ability to draw generalization from the findings of this review. Second, the search terms and the study selection described in this protocol have been selected based on the expertise of the research team in the areas of anesthesiology, intensive care medicine, technology, and evidence research, as well as the existing literature, rather than according to pre-existing research frameworks or categories. This may represent a bias that the research team will need to consider when discussing the findings of the scoping review.

Conclusions

We found that sufficient literature is available to complete the remaining steps of the methodology. To our knowledge, this is the first scoping review to examine the use of telemedicine in intensive care with a focus on the implementation context. Our research will contribute to the identification of where more evidence is needed to support the development of tele-ICU technology, with the appropriate configuration for its context and use case. The need for future research contributions and systematic reviews will be identified.

Acknowledgments

We acknowledge support from the German Research Foundation (DFG) and the Open Access Publication Funds of Charité–Universitätsmedizin Berlin.

Conflicts of Interest

BW received personal fees for consultancy and speaking from ORION Pharma Ltd, outside the submitted work. The other authors have no conflicts to declare.

Multimedia Appendix 1

Search query.
[DOCX File , 45 KB-Multimedia Appendix 1]

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Abbreviations

ICU: intensive care unit
NICU: neonatal intensive care unit
PICU: pediatric intensive care unit

Edited by G Eysenbach; submitted 15.06.20; peer-reviewed by H Park, T Aslanidis; comments to author 01.08.20; revised version received 31.08.20; accepted 10.11.20; published 31.12.20

Please cite as:
Guinemer C, Boeker M, Weiss B, Fuerstenau D, Balzer F, Poncette AS
Telemedicine in Intensive Care Units: Protocol for a Scoping Review
JMIR Res Protoc 2020;9(12):e19695
URL: http://www.researchprotocols.org/2020/12/e19695/
doi: 10.2196/19695
PMID:

Publication 2: Scoping Review

J Med Internet Res

2021 Nov 3;23(11):e32264.

Telemedicine in Intensive Care Units: Scoping Review

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PMID: 34730547 PMCID: PMC8600441 DOI: 10.2196/32264

Review

Telemedicine in Intensive Care Units: Scoping Review

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Abstract

Background: The role of telemedicine in intensive care has been increasing steadily. Tele–intensive care unit (ICU) interventions are varied and can be used in different levels of treatment, often with direct implications for the intensive care processes. Although a substantial body of primary and secondary literature has been published on the topic, there is a need for broadening the understanding of the organizational factors influencing the effectiveness of telemedical interventions in the ICU.

Objective: This scoping review aims to provide a map of existing evidence on tele-ICU interventions, focusing on the analysis of the implementation context and identifying areas for further technological research.

Methods: A research protocol outlining the method has been published in JMIR Research Protocols. This review follows the PRISMA-ScR (Preferred Reporting Items for Systematic Reviews and Meta-Analyses Extension for Scoping Reviews). A core research team was assembled to provide feedback and discuss findings.

Results: A total of 3019 results were retrieved. After screening, 25 studies were included in the final analysis. We were able to characterize the context of tele-ICU studies and identify three use cases for tele-ICU interventions. The first use case is *extending coverage*, which describes interventions aimed at extending the availability of intensive care capabilities. The second use case is *improving compliance*, which includes interventions targeted at improving patient safety, intensive care best practices, and quality of care. The third use case, *facilitating transfer*, describes telemedicine interventions targeted toward the management of patient transfers to or from the ICU.

Conclusions: The benefits of tele-ICU interventions have been well documented for centralized systems aimed at extending critical care capabilities in a community setting and improving care compliance in tertiary hospitals. No strong evidence has been found on the reduction of patient transfers following tele-ICU intervention.

International Registered Report Identifier (IRRID): RR2-10.2196/19695

(J Med Internet Res 2021;23(11):e32264) doi: 10.2196/32264

KEYWORDS

tele-ICU; telemedicine; critical care; implementation; telehealth; health care system; intensive care unit; health technology; digital health; care compliance; tertiary hospitals; hospital; review

Introduction

Telemedicine has been increasingly used in intensive care, and approximately 15% of intensive care beds in the United States currently partake in telemedical programs [1-3]. A range of rationales for the implementation of telemedical systems in intensive care has been suggested. Tele–intensive care unit (ICU) technologies have been used to address staffing shortage in intensive care and as a cost-effective response not only to a lack of intensive care availability in some areas but also as a means of increasing adherence to evidence-based best practices using benchmark performance data [3-5].

The American Telemedicine Association defines tele-ICU as "a network of audiovisual communication and computer systems that provide the foundation for a collaborative, interprofessional care model focusing on critically ill patients" [3]. Tele-ICU interventions are varied, can be offered in different levels of intensive care service, and can be customized to meet the specific intensive care needs of hospitals [3,5-7]. For example, some tele-ICU systems provide 24/7 remote monitoring staffed by intensivists, while other systems provide scheduled remote intensivist consultations during nighttime only.

The main characteristics of tele-ICU systems have been well described in the literature. First, technical architectures can be described as centralized or decentralized. Centralized architecture features a command center, or a *cockpit*, connecting one or multiple centers. Decentralized systems (also named *virtual consultant*) allow one-on-one connections without the need for central coordination [3]. Second, staff allocation and availability can vary (eg, day presence or 24/7) [8]. Third, the mode of interaction between telemedicine teams and bedside staff may allow various levels of staff reactivity (reactive vs proactive to patient alerts) and intervention scope (minimal intervention allowed vs full discretion on patient care) [4]. Several guidelines, such as the US [3] or the German Guidelines for Telemedicine in Intensive Medicine [9], provide general recommendations on aspects of equipment, staffing, and organization for implementing tele-ICU systems.

A significant body of primary and secondary literature has been published on ICU telemedical interventions [10]. To date, 9 systematic reviews and 9 other review types have been published on this topic [11], as well as 3 meta-analyses with a focus on medical outcomes (eg, hospital mortality and length of stay) [12]. In previous reviews, the results of tele-ICU interventions have been characterized as heterogeneous [13,14]. Although positive medical outcomes could be detected in some interventions, other contexts could only demonstrate mixed or no positive results at all [4,14,15]. Authors have suggested that the context of implementation may be a factor in explaining the variability of these results. We define context of implementation as the clinical structures and processes where telemedical interventions are deployed [16]. It has been suggested that the efficacy of tele-ICU interventions is dependent on where and how they are deployed in the organization [6,10], and there is a need for broadening the understanding of the organizational factors influencing the efficacy of tele-ICU interventions [8]. We found that no previous study has attempted to provide a review of current evidence by systematically analyzing the implementation setup and context.

This scoping review seeks to address a research gap on the characterization of the context of implementation for tele-ICU interventions [14,17]. The first objective is to characterize the implementation context of tele-ICU interventions with a consistent set of domains on hospital organization. The second objective is to characterize the configurations and structures of tele-ICU systems in relation to their context of implementation. The third objective is to describe the outcomes of tele-ICU interventions and to characterize current evidence according to their intervention contexts.

Methods

A research protocol for this review was published in JMIR Research Protocols in December 2020 [11], which was developed in accordance with the PRISMA-ScR (Preferred Reporting Items for Systematic Reviews and Meta-Analyses Extension for Scoping Reviews) and best practices advanced by Arksey and O'Malley [18] and the Joanna Briggs Institute [19]. The method included the steps *identification of relevant studies*, *selection of study*, *data charting*, and *data collating*.

For the step *identification of relevant studies*, a search for peer-reviewed studies in the databases Web of Science Core Collection, MEDLINE, ERIC, PsycINFO, PSYNDEX, CINAHL, and IEEE was performed without date restrictions. Manual searches were performed additionally to identify gray literature. The search query was developed according to the guidelines of the Peer Review of Electronic Search Strategies and included keywords on the topics of intensive care and telemedicine. The full queries are provided in Multimedia Appendix 1. The search records were downloaded in the reference software Citavi version 6 (Swiss Academic Software).

In the step *selection of study*, both titles and abstracts were screened, and studies not dealing with a relevant topic or method were removed. Results were then screened to find articles where the PICO (Patient, Intervention, Comparison, Outcome) framework could be identified. We included articles with at least three of the PICO criteria summarized in Textbox 1. Studies concerning interventions in neonatal and pediatric ICUs were excluded from this scoping review.

In the step *data charting*, article information was collected and classified into extraction sheets according to the five domains defined in the review protocol (see Textbox 2).

In the step *data collating, summarizing, and reporting*, the information was organized and clustered into an evidence map. The evidence map provided a summary of the scoping review results. During the review process, a core research team was created to provide feedback and discuss findings. The research team was composed of a doctoral researcher with a background in health economics (author CG), a medical data science professor (author FB), a medical informatics professor (author MB), an anesthesiologist with intensive care specialty and main coordinator of a tele-ICU project (author BW), an anesthesiology researcher with a specialty in digital health (author ASP), a professor of digitalization (author DF), and an anesthesiologist with intensive care specialty (author RM). The research team was asked to consider the information from data charting, provide insights, and discuss results. Differing views were resolved through discussion until consensus was reached.

Textbox 1. PICO (Patients, Intervention, Comparison, Outcomes) criteria.

Patient

Participants provided telemedical intensive care.

Intervention

Telemedical system implemented with one more an intensive care units (ICUs).

Comparison

Comparison with the standard of care without tele-ICU intervention.

Outcomes

All outcomes eligible for inclusion.

Textbox 2. Data charting domains.

Implementation context

A. Clinical focus

Level of intensive care specialization. Generalist (medical intensive care unit [ICU], surgical ICU) or specialized clinical focus (ie, sepsis, cardiology, neurocritical).

B. ICU type

Level of intensivist involvement in patient care. Defined by staffing model of ICU (ie, open vs closed ICU models).

C. Hospital type

Category of hospital involved in tele-ICU intervention (ie, tertiary or community hospital). Community hospitals are defined as nonfederal, short-term general hospitals under 500 beds [20].

D. System configuration

Technical architecture (ie, centralized vs decentralized), staff allocation (ie, continuous vs scheduled), and mode of communication of the tele-ICU system (ie, high or low data intensity).

E. Implementation rationale

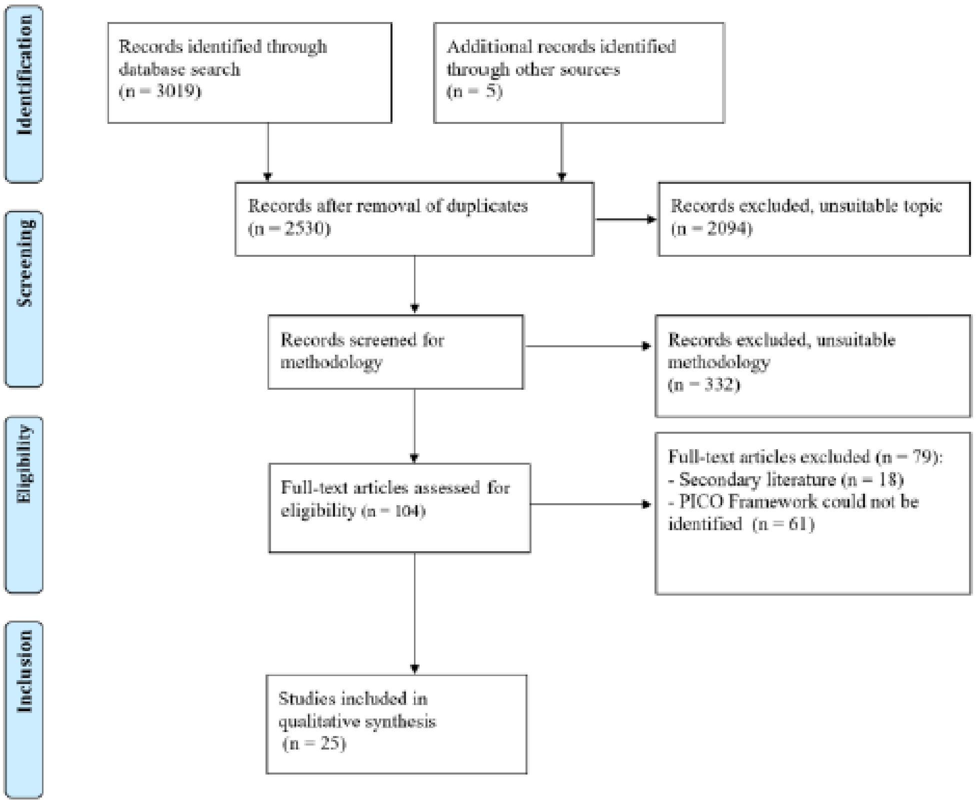
Main rationale provided in the study for tele-ICU intervention, use case for telemedical system in the ICU.

Results

Selection of Relevant Studies

The flowchart in Figure 1 outlines the records yielded by the search. A total of 3019 results were retrieved, including 489 duplicates. After screening, 104 records were eligible for full-text analysis and 25 were included in the final analysis.

Figure 1. PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) flowchart. PICO: Patient, Intervention, Comparison, Outcomes.



Characteristics of Tele-ICU Studies Included in the Scoping Review

The 25 studies included in this review were published between 2004 and 2019. Out of 25 articles, 21 (84%) referred to tele-ICU implementation within the Unites States, while the remaining papers described implementation in Germany, India, Australia, and Saudi Arabia. Regarding the research methods used in the studies, we found that 21 articles used pre-post comparison designs, of which only 7 included a control group. The pre-post design has been described as a quasi-experimental research design [12,21], for which a random assignment of patients between treatment and control group was not performed. The remaining 4 publications used other methods, such as interrupted time series, and half of these included a control group. We found no examples of randomized controlled trials.

Results From Data Charting

Table 1 summarizes the data charting results for the 5 research domains and provides definitions for each category.

First, we outline results for the domains pertaining to context of implementation (domains A to C). For domain A, most telemedical implementations did not have a specific clinical focus (n=21, 84% of the studies), with only a few cases of specialized interventions. For domain B, tele-ICU interventions were predominantly implemented in ICUs featuring aspects of the open model. In these interventions, the primary physicians or surgeons retained full responsibility for the patient (n=10, 40% of the studies) or with limited intensivist involvement only (n=9, 36% of cases open/closed). Regarding domain C, although 44% (n=11 studies) of interventions were implemented in tertiary hospitals, a large subset was in community settings and in organizations spanning both tertiary and community hospital settings.

Second, concerning the system configuration results in domain D, centralized architectures (eg, tele-ICU Command Center) were the predominant implementation setup. Relating to the staffing model, the continuous care setup was used in 13 (52%) of the studies, where the remote care team assumes constant patient monitoring. Scheduled interventions (eg, daily intensive care rounds) were found in 9 (36%) cases. Finally, most telemedical systems (n=19, 76%) enabled remote real-time access to patient data. To summarize this information, we classified the system configurations into three clusters, as outlined in Figure 2.

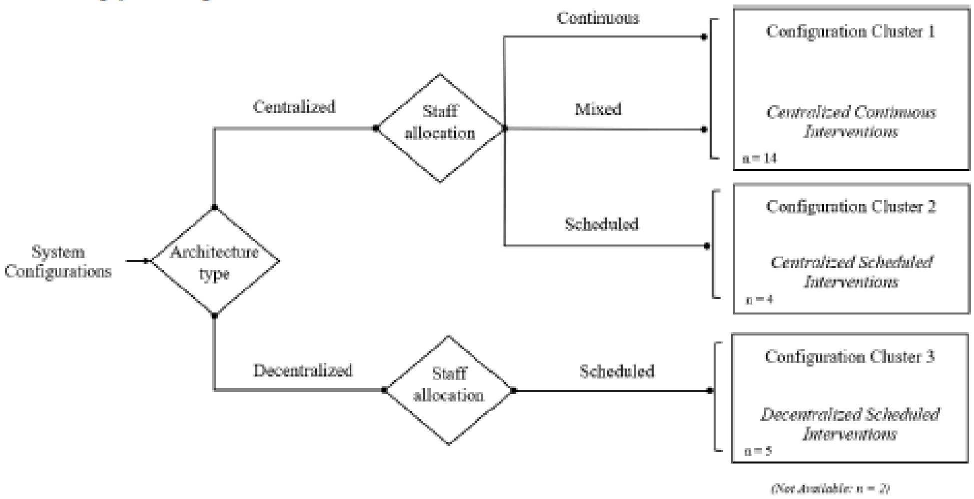
Finally, concerning the implementation rationale defined in domain E, three main use cases were defined for tele-ICU interventions. We classified 13 (52%) publications under the use case 1 summarized by the term *extending coverage*. In this group, studies cited intensivist shortage, need for additional intensivist coverage, and extension of intensivist resources as a rationale for the intervention. A total of 10 (40%) studies were classified under use case 2, summarized by the term *improving compliance*. In this group, studies cited the increase in adherence to compliance with care bundles, clinical practice guidelines, or care quality initiatives as the main rationale. We classified two studies in use case 3, summarized by the term *facilitating transfer*. Studies in this category cited the screening or monitoring of patients prior to transfer to or from an ICU as the main rationale.

Table 1. Data charting results: interventions and context.

Domain and category	Definition	Studies (N=25), n (%)
Implementation context		
Clinical focus		
General	No specific clinical focus identified (MICU[a], SICU[b])	21 (84)
Specialized	Specific clinical focus (ie, sepsis, cardiology, neurocritical)	4 (16)
ICU[c] type		
Open	Primary physician has full-time responsibility for patient care	10 (40)
Open/closed	Features of both open and closed models	9 (36)
Closed	Intensivists available with full responsibility for patient care	6 (24)
Hospital type		
Tertiary	Tertiary care institutions or teaching hospitals	11 (44)
Mixed	Care organization spanning tertiary and community settings	4 (16)
Community	Community hospitals or small medical facility	9 (36)
Not available	N/A[d]	1 (4)
System configuration		
Continuous	Continuous patient critical care monitoring	5 (20)
Mixed	Continuous monitoring including scheduled rounds	9 (36)
Scheduled	Scheduled consultation at regular interval. Virtual rounds.	9 (36)
Not available	Insufficient information provided	2 (8)
Centralized	Tele-ICU Command Center or Hub centralizing patient care	19 (76)
Decentralized	Distributed architecture without centralized hub	5 (20)
Not available	N/A	1 (4)
Direct access	Direct staff remote access to patient data	18 (72)
Limited access	Limited staff remote access (screen sharing) to patient data	4 (16)
Not available	N/A	3 (12)
Implementation rationale		
Coverage	Intensivist shortage, provision of extended coverage	13 (52)
Compliance	Adherence and compliance to critical care guidelines	10 (40)
Transfer	Patients screening or triage for transfers to or from ICU	2 (8)

[a]MICU: medical intensive care unit.
[b]SICU: surgical intensive care unit.
[c]ICU: intensive care unit.
[d]N/A: not applicable.

Figure 2. Clustering system configurations.



Intervention Outcomes

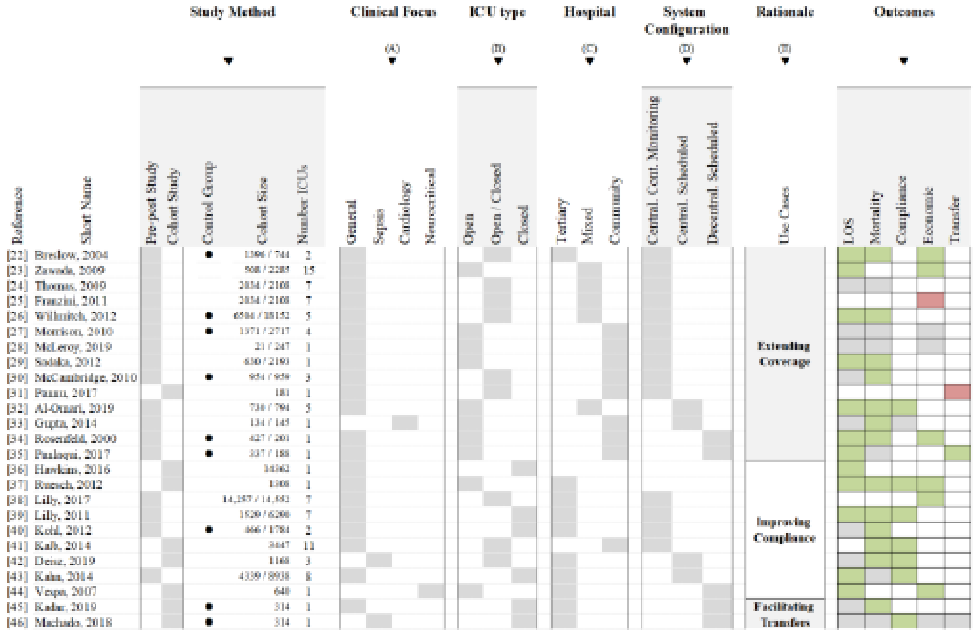
This section presents results on the range of outcomes that were found in the studies on ICU implementation, which are summarized in Table 2.

First, a significant subset of studies provided results on at least one medical outcome. Effect of tele-ICU intervention on length of stay (LOS) was reported in 21 (84%) studies. This outcome was defined as the number of inpatient days for the episode of care in the ICU or in aggregate in the hospital. Results on mortality rates were provided in 19 (76%) studies, including ICU and hospital mortality. In 12 studies, reduction in LOS was found to be significant. Reduction in mortality was significant in 13 studies. Second, 8 (32%) studies measured the rate of adherence to best practices and guidelines implementation, summarized by the term *compliance*. A large subset indicated a statistically significant increase in the level of adherence to ICU standards. Third, under the header *economics*, 9 (36%) studies provided results regarding cost-effectiveness of tele-ICU interventions. In this subset, 6 (67%) studies reported interventions as being cost-effective. Lastly, 2 studies in the category *transfer* measured changes in rate of patient transfer following intervention. One study measured the number of transfers within the same facility (eg, for preadmission diagnostic) and another the number of transfers to another facility (eg, for advanced care). Finally, we note that none of the studies included patient satisfaction scores. These results are summarized as an evidence map in Figure 3.

Table 2. Data charting results: outcomes.

Outcome category	Reporting on outcome, n	Of which reporting positive results, n
Length of stay	21	12
Mortality	19	13
Compliance	8	7
Economics	9	6
Transfer	2	1

Figure 3. Evidence map [22-46]. ICU: intensive care unit; LOS: length of stay.



Discussion

Principal Findings

This scoping review provided an overview of the literature on telemedical interventions in the ICU. Based on a set of defined domains, we were able to characterize the context of tele-ICU studies and identify three use cases for tele-ICU interventions. This analysis aimed to identify common features within the heterogenous use of telemedical systems. Recent research findings relevant for implementation under each use case were outlined.

The first use case, *extending coverage*, included interventions aimed at increasing intensive care coverage in contexts where it is not (or only partially) available at the bedside. This use case was found predominantly in community hospitals having limited onsite critical care capacity. The second use case, *improving compliance*, included interventions targeted at improving patient safety, intensive care best practices and quality of care. These interventions were found primarily in tertiary care context. The third use case, *facilitating transfer*, included telemedicine interventions targeting toward the management of patient transfers to or from the ICU.

Use Case: Extending Coverage

Interventions were predominantly found in community hospitals and in mixed community/tertiary contexts (eg, hospital groups spanning one or several community branches). Tele-ICU systems in this use case have been used to address specific issues related to the delivery of critical care in community and rural areas. Particularly in the United States, recent surveys indicate that hospitalists (ie, physicians whose main focus is on general medical care of patients who are hospitalized [47]) are still the main physician in rural and community settings, reflecting a general shortage in intensive care staffing [48]. Although community hospitals face difficulties in hiring qualified critical care personnel, some of them are subject to minimum requirements to have full intensivist staffing during the day [49,50]. In underserved areas, tele-ICU implementation can therefore represent a valuable solution for the onsite provision of intensive care expertise [51].

The predominant tele-ICU system configuration in this use case was a centralized system featuring continuous remote staff intervention from a workstation, with direct involvement in patient care (configuration cluster: *centralized continuous monitoring*). Team cooperation and sharing of responsibility over patient care between the bedside and remote team are central issues in this type of configuration. Our analysis showed that different modalities of a remote care team have been implemented. In some interventions, the main role of the remote team was to consult and advise the bedside team (Zawada et al [23], McLeroy et al [28], and Al-Omari et al [32]; n=3, 12% of studies), whereas in other cases, remote staff were granted a different level of authority on patient care at the discretion of the bedside team (Sadaka et al [29], Morrison et al [27], Thomas [24], Willmitch et al [26], Franzini et al [25], and Breslow et al [22]; n=6, 24% of studies). Achieving an appropriate degree of cooperation between bedside and remote care has been described as a success factor of telemedical interventions [10,52]. Recent literature on the impact of tele-ICU interventions suggest that effectiveness is enhanced when comanagement and clear autonomy of the remote care team are allowed [10,36].

Particularly for intensive care nurses, there is a need to establish clear rules of engagement to avoid conflicting orders between bedside and remote teams [53]. A recent ethnographic review also indicates that the perceived value of the intervention by bedside staff is a contributing factor to the success of the intervention [14]. The core research group discussed in particular the aspect of bedside physician's trust in the remote specialist. As an example, situations where an experienced physician of a nonacademic hospital in a rural area collaborates with a less experienced physician at a university hospital telemedical center can raise the issues of perceived value and trust between remote and bedside personnel. Therefore, the involvement of bedside staff during planning, system implementation, and training is recommended to enhance organizational acceptance [54,55]. As part of the implementation process, actions targeted at team cohesion (eg, team building) and use of standardized communication practices between teams can enhance the implementation of new workflows [56,57]. Implementation of health technology can lead to changes in work practice inside the care team, in particular for nursing and support staff [58]. Clear definition of the roles, responsibility, and composition of the team should therefore be addressed early on during the planning of the intervention.

Implementation of tele-ICU systems has been advanced as a solution for community hospitals facing the challenge of sustaining the cost of maintaining a local ICU with high standard of care. Economic evaluations of tele-ICU interventions are therefore an important aspect for consideration in the community settings. With tele-ICU systems, community hospitals have the potential to treat patients with a higher case mix index locally and at lower cost [51]. At the same time, high cost of tele-ICU systems has been described as a barrier to implementation [59]. Our finding indicates that studies on cost-effectiveness in this use case have not yielded uniform results. The included studies in this review have used heterogeneous approaches to estimate savings and revenue increase following tele-ICU implementation. We corroborate previous observations concerning the lack of transparency and comprehensive data on costs, which hinder comparisons and clear statements regarding cost-efficacy [59,60].

Use Case: Improving Compliance

In this use case, ICU systems were primarily configured as scheduled daily rounds from a tele-ICU center (configuration cluster *centralized scheduled interventions*; n=4, 16% of studies) and decentralized systems allowing expert remote consultations (configuration cluster *decentralized scheduled interventions*; n=5, 20% of studies). Interventions in the use case are mainly focused on advancing adherence to best practices in the ICU and increasing patient safety. They consisted in establishing critical care processes in which the remote care teams monitor relevant quality indicators (eg, prophylaxis for stress ulcer, ventilator-associated pneumonia, or deep vein thrombosis). In our analysis, there is some evidence that ICU interventions are conducive to higher adherence to best practices in the ICU and enhance patient safety, thereby corroborating earlier observations on efficacy [51]. We found that most evidence for this type of intervention has been reported in tertiary care hospitals with a closed or mixed ICU model. Additional research would be needed to understand how this type of intervention could be beneficial in other hospital contexts. The review highlighted an intervention specialized on prevention of sepsis (Deisz et al [42]), for which compliance to the care bundle was found to remain low [61,62].

We hypothesize that the efficacy of these interventions is derived from a combination of change in the care process (eg, increased use of reminders and checklists) and the use of decision support systems (eg, smart alerts). Tele-ICU systems are conducive to real-time benchmarking of performance and allow targeted actions to enhance compliance and care quality. Surveillance systems can improve resource allocation by allowing for more rapid response time and faster escalation of the most acute cases [54]. Additionally, tele-ICU systems have been shown to reduce alarm fatigue through triage and curation of automatic alerts by remote care teams [51,59]. In recent literature, the potential of population management systems allowing targeted interventions on patients with high risk factors has been highlighted [63]. Significant amount of data generated by tele-ICU systems can be leveraged for the development of advanced applications [64]. A recent systematic review on telemedicine with clinical decision support for critical care indicated the need for further research on the use and efficacy of advanced applications in units equipped with telemedical systems [65].

Use Case: Facilitating Transfer

Interventions in this use case are aimed at supporting patient transfers between hospitals (ie, referral to higher level hospital) and monitoring patients during admission in the ICU from another department (eg, emergency department). This form of intervention has been described in the literature as consultative critical care services [66]. One study in the review documented the benefit of these interventions for patients in the emergency department with suspected sepsis diagnosis [54]. Based on the studies in the review, we can corroborate previous reports that no strong evidence has been found regarding the benefit on the number of transfers for this type of interventions [67].

Limitations

Our approach has multiple limitations. First, the studies included in the review used heterogeneous research methods. Authors provided varying degree of details to describe the intervention setup and implementation context. Aspects such as staff interaction and level of autonomy have been provided only in a limited number of studies, so that our ability to draw generalizable conclusions on these aspects of tele-ICU interventions has been limited. Second, relying on the expertise of the core research group to complete the data charting was qualitative in nature and potentially subject to bias. A discussion process section was established to mitigate the interpretation bias in our approach. Third, the scope of this review was limited to the implementation of tele-ICU systems for adult patients, and critical care telemedical interventions have also been documented in pediatrics and neonatology. Some of our conclusions might therefore not be applicable to these settings.

Conclusion

Tele-ICU systems have been deployed in numerous implementation contexts, which we characterized in three main use cases. The benefits of tele-ICU interventions have been well documented for centralized systems aimed at extending critical care capabilities in community settings and improving care compliance in tertiary hospitals. This scoping review provides teams involved in the implementation of tele-ICU systems with an overview of existing evidence on the technology. It highlights factors that are conducive to successful implementation for different critical care context. This review also mentions areas for future research on tele-ICU interventions. Furthermore, the framework for describing the implementation context used in this scoping review could be used for analyzing other types of telemedical interventions or other domains of intervention (eg, traumatology, pediatrics, neonatology).

Acknowledgments

We acknowledge support from the German Research Foundation and the Open Access Publication Funds of Charité–Universitätsmedizin Berlin. ASP is a participant in the Digital Clinician Scientist Program funded by the Charité–Universitätsmedizin Berlin and the Berlin Institute of Health.

Conflicts of Interest

None declared.

Multimedia Appendix 1

Search queries for peer-reviewed studies in literature databases.
[PDF File (Adobe PDF File), 54 KB-Multimedia Appendix 1]

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Abbreviations

ICU: intensive care unit
PICO: Patient, Intervention, Comparison, Outcome
PRISMA-ScR: Preferred Reporting Items for Systematic Reviews and Meta-Analyses Extension for Scoping Reviews

Edited by G Eysenbach; submitted 26.07.21; peer-reviewed by HS Kim, T Koritala, B Wolfe-Piggott; comments to author 26.08.21; revised version received 03.09.21; accepted 18.09.21; published 03.11.21

Please cite as:
Guinemer C, Boeker M, Fürstenau D, Poncette AS, Weiss B, Mörgeli R, Balzer F
Telemedicine in Intensive Care Units: Scoping Review
J Med Internet Res 2021;23(11):e32264
URL: https://www.jmir.org/2021/11/e32264
doi: 10.2196/32264
PMID:

Curriculum Vitae

Mein Lebenslauf wird aus datenschutzrechtlichen Gründen in der elektronischen Version meiner Arbeit nicht veröffentlicht.

Publication list

- Guinemer C, Boeker M, Weiss B, Fuerstenau D, Balzer F, Poncette A-S. Telemedicine in Intensive Care Units: Protocol for a Scoping Review. JMIR Res Protoc 2020 Dec – Impact Factor N/A
- Guinemer C, Boeker M, Fürstenau D, Poncette A-S, Weiss B, Mörgeli R, Balzer F. Telemedicine in Intensive Care Units: Scoping Review. J Med Internet Res 2021 Nov 3;23(11):e32264. [doi: 10.2196/32264] 31;9(12):e19695. [doi: 10.2196/19695] – Impact Factor 5.428

Acknowledgments

I would like to thank my supervisors Prof. Martin Boeker and Prof. Felix Balzer for their constant encouragement and support.

I would also like to thank the co-authors of the joint publication, namely Prof. Daniel Fürstenau, Dr. Akira Poncette, Dr. Björn Weiss and Dr. Rudolf Mörgeli for their great support and constructive discussions.