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RESEARCH PAPER

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Innovation in devices for newborn stability during transport: a systematic literature review

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ABSTRACT

The transportation of newborns, particularly in neonatal care, presents significant challenges in maintaining their physiological stability. Neonates are highly vulnerable to conditions such as hypothermia, respiratory distress, and cardiovascular instability, which can arise during transit and lead to severe complications or even mortality. Ensuring effective stabilization during transport is crucial to improving neonatal outcomes, particularly for preterm and critically ill infants. This study aims to explore the advancements in neonatal transport stabilization devices, with a specific focus on real-time monitoring systems designed to mitigate the risks associated with transport. A systematic literature review was conducted to examine recent innovations in the design, functionality, and implementation of these devices. The findings highlight significant progress in neonatal transport technology, including improvements in temperature regulation, respiratory support, and cardiovascular monitoring. Many modern devices now integrate advanced sensors, automated control mechanisms, and wireless data transmission, allowing continuous assessment of a newborn's condition in real time. Additionally, the development of portable and energy-efficient designs has enhanced their practicality in various clinical settings. However, despite these technological advancements, challenges remain in terms of cost, accessibility, and implementation, particularly in low-resource settings where neonatal transport services are often limited. The high costs of these devices and the need for specialized training to operate them effectively hinder their widespread adoption. In conclusion, advancements in neonatal transport stabilization devices hold great potential for improving safety and survival rates in high-risk newborns. Future research and development should focus on making these technologies more cost-effective, accessible, and adaptable to diverse healthcare settings, ensuring that all newborns receive optimal care during transport.

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1. INTRODUCTION

The newbon period is a critical phase in human development, marked by rapid physiological changes and heightened vulnerability to external factors. During this phase, maintaining physiological stability is particularly challenging, especially during the transfer between care facilities [1]. Premature or low birth weight newborns are particularly vulnerable to a range of serious complications due to their underdeveloped physiological systems. These infants are at heightened risk for hypothermia, as their limited fat stores and immature thermoregulatory mechanisms make it difficult to maintain stable body temperature [2].

This, in turn, can exacerbate metabolic demands, placing additional strain on their already fragile systems. Additionally, these newborns are prone to respiratory distress, often caused by immature lungs that may lack sufficient surfactant, leading to difficulty in oxygen exchange and increased risk of respiratory failure. Cardiovascular instability is another critical concern, as their immature heart and circulatory system may struggle to maintain adequate perfusion and blood pressure, further complicating their ability to cope with stressors [3]; [4]. Together, these risks contribute to a higher incidence of morbidity and mortality, with potential long-term developmental impairments that can affect their overall quality of life and healthcare outcomes. Effective interventions during transport and care are essential to

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minimize these risks and ensure better survival and recovery prospects [5].

Hypothermia is one of the most common and harmful complications encountered during the transfer of newborns. Even a minor drop in body temperature can trigger a cascade of serious health issues, such as elevated metabolic demands, respiratory distress, and compromised cardiac function. These complications arise because newborns, particularly premature or critically ill infants, have limited capacity to regulate their own body temperature. Studies have consistently shown that neonates who become hypothermic during transport are at significantly higher risk for both short-term morbidity and long-term health complications, as well as increased mortality rates. This evidence highlights the critical need for effective thermal management strategies to ensure newborns remain within a safe and stable temperature range throughout the transport process. Maintaining thermal stability is essential not only for immediate survival but also for reducing the likelihood of future complications, making it a key focus of neonatal care during transport [6]; [7]; [8].

Traditionally, manually operated incubators or basic warming devices have been employed for newborn transport. However, these conventional methods often fall short of providing optimal control over the infant's environment, particularly in terms of continuous real-time monitoring and timely intervention. The absence of sophisticated monitoring systems increases the likelihood of adverse outcomes, as there is often a delay in detecting and responding to changes in the newborn's physiological status [9]. This delay in detection reduces the window for timely intervention, which is crucial in preventing the rapid deterioration of the infant's health. Additionally, manual monitoring methods or devices that lack automated alert systems rely heavily on the constant vigilance of caregivers, increasing the potential for human error.

In recent years, technological progress has led to the creation of innovative solutions designed to enhance the safety and effectiveness of neonatal transport. These technological advancements specifically aim to minimize the risk of complications during transit by maintaining stable environmental conditions and providing continuous monitoring of newborns' vital signs. A key innovation in this field is the development of integrated transport systems equipped with advanced monitoring devices. These systems include temperature sensors to regulate thermal stability, respiratory sensors to track breathing, heart rate monitors, as well as gyroscopes to monitor movement and position, and cameras for real-time visual assessment. Together, these tools ensure that healthcare professionals can closely monitor newborns throughout transport, promptly addressing any issues that may arise, thereby improving overall outcomes [10].

The emergence of these technologies addresses a critical gap in neonatal care: the need for continuous real-time monitoring during transport. For instance, devices such as the devices for transporting the baby have been designed to maintain newborn stability during transit by providing real-time data on vital signs and automatically adjusting environmental conditions, such as temperature. This comprehensive monitoring system offers caregivers the ability to intervene promptly and effectively when needed, significantly reducing the risk of hypothermia and other complications. Caregivers may also visually watch the baby during the travel process thanks to the camera's integration, ensuring that any signals of discomfort are promptly addressed [9].

Many of the drawbacks of conventional transport techniques are addressed by the gadget, which offers automatic modifications and constant monitoring. Its application may result in better overall outcomes for neonates in need of specialist care as well as a decrease in the frequency of difficulties linked to transportation. The need for creative solutions that improve patient safety and care quality is growing as healthcare systems continue to change. This tendency is supported by the development of gadgets or other devices which provide a useful and efficient means of handling the complicated requirements of neonates while in transit. One innovative strategy for resolving the issues surrounding neonatal transport is the incorporation of cutting-edge monitoring technologies into newborn care [11]; [12].

However, despite the progress made in this field, there is a need for a systematic review of the current literature to evaluate the effectiveness of these technologies. Previous studies have explored various aspects of neonatal transport systems, but a comprehensive synthesis of the available evidence is lacking. This systematic literature review aims to consolidate and critically assess existing research on device development for ensuring newborn stability during transport. By identifying trends, evaluating the efficacy of different approaches, and highlighting gaps in current knowledge, this review seeks to provide a foundation for future innovations and improvements in neonatal transport systems.

2. MATERIALS AND METHOD

This systematic literature review was conducted to evaluate the current advancements in devices designed for ensuring newborn stability during transport. The methodology follows the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines to ensure a comprehensive and unbiased selection of studies.

The use of PRISMA ensures a comprehensive and unbiased selection of studies, minimizing the risk of bias in data collection and interpretation. Specifically, the process involves several key stages, including a systematic search of multiple databases, the application of clear inclusion and exclusion criteria, and a detailed screening process to filter studies based on relevance. This method also includes the use of a PRISMA flow

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diagram, which visually represents the number of studies identified, screened, and ultimately included in the review, allowing for transparency in the decision-making process. In a systematic review, there are several potential biases that can affect the results. Therefore, it is important to identify, understand, and reduce biases so that the conclusions produced remain valid and reliable.

By selecting the Prisma Method, this study can ensure a transparent selection process, minimize bias, and increase the credibility and reproducibility of the findings. This makes PRISMA the most appropriate approach compared to other systematic review methodologies in the context of this study. The following steps outline the research process:

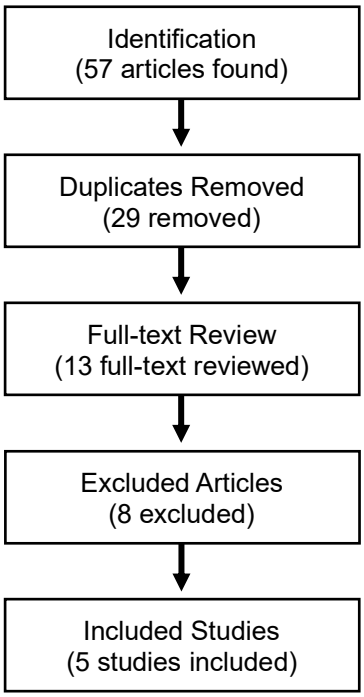

Fig. 1. **PRISMA flow diagram**

A. Search Strategy

The research process began by defining the key objectives and research questions, which guided the selection of appropriate methodologies for data gathering and analysis. A comprehensive search of academic databases was performed across several major databases, including PubMed, Scopus, IEEE Xplore, and Google Scholar, to locate relevant studies published within the timeframe of 2014 to 2024.

- PubMed - This database is widely used in the medical and health fields, covering leading journals published by the National Library of Medicine (NLM). PubMed is particularly relevant to the topic of neonatal transport, as it covers clinical studies, care protocols, and medical technology developments related to newborn care.
- Scopus - As a multidisciplinary database covering a wide range of disciplines, including medicine, engineering, and health sciences, Scopus provides extensive coverage of research related to neonatal transport technology, medical devices, and global health policy.
- Web of Science - Has an extensive academic citation index, helping in searching literature that has a major impact in the field of health and medical technology.
- IEEE Xplore - If the study being conducted involves aspects of medical device engineering or neonatal transport technology development, this database can provide information on technical innovations and engineering-based solutions.

The search strategy utilized various combinations of keywords, such as "newborn transport stability," "neonatal transport devices," "real-time monitoring in neonatal care," and "hypothermia prevention in newborns," to capture a broad spectrum of research on the topic. After removing duplicates, the remaining articles were screened based on titles and abstracts, and only those meeting the inclusion criteria proceeded to full-text review. The quality of the selected studies was assessed using standardized tools to ensure reliability. Data from these studies were then systematically extracted and synthesized, with key findings summarized to draw conclusions. The extracted data was analyzed to identify trends and gaps in the literature, and the results were interpreted in relation to the research objectives. Finally, a comprehensive report was compiled, discussing the implications for future research, clinical practice, and policy-making in neonatal transport stability.

B. Inclusion and Exclusion Criteria

To ensure the relevance of the studies included in the review, specific inclusion criteria were applied. The studies selected had to focus on devices or technologies designed to stabilize newborns during transport. Only research articles published in peer-reviewed journals or presented at international conferences were considered, and all articles needed to be available in English. Additionally, the studies had to involve newborns or premature infants undergoing transport.

In contrast, certain exclusion criteria were also applied. Studies that did not focus on the development of devices or stabilization technologies were excluded. Articles that lacked sufficient data or details on device performance and outcomes were also omitted. Studies that were not peer-reviewed or published in reputable scientific journals were also excluded. Finally, case studies or reports with a sample size of fewer than five patients were excluded to maintain the robustness of the review. The evaluation of sample size in the reviewed studies ensured reliability and validity. Larger samples enhance statistical power, improve generalizability, and reduce inter-subject variability. Study design also plays a role, as observational studies and RCTs require different sample

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size standards, particularly for detecting meaningful differences in intervention groups. Excluding studies with fewer than five patients mitigated key limitations. Small samples often yield unstable, non-generalizable results and are prone to selection and publication bias. In meta-analysis, their inclusion can distort findings due to outliers, reducing accuracy.

This exclusion criterion strengthened research findings by ensuring robust data synthesis, improving reliability, and minimizing bias. It was especially crucial in neonatal transport research, where clinical variability affects intervention effectiveness. These measures enhanced the validity and applicability of conclusions.

C. Study Selection Process

The initial search yielded a total of 57 articles. After removing duplicates, 28 articles were screened based on their titles and abstracts. From this, 13 articles were selected for full-text review. The research process involved several critical steps to ensure the inclusion of only the most relevant and high-quality studies. Each article was meticulously assessed based on a set of predefined inclusion and exclusion criteria. These criteria were designed to filter studies according to specific factors, such as the characteristics of the study population (e.g., newborns or neonatal patients), the type of intervention being tested (e.g., tools or methods used for ensuring stability during transport), the outcomes measured and the publication date to ensure the data was up-to-date.

This systematic evaluation process helped ensure that only studies aligned with the research objectives were selected for further analysis. Additionally, the methodological rigor of each study was considered to ensure it provided reliable data. During this process, 8 articles were excluded due to insufficient quality, irrelevance, or lack of focus on the specific outcomes of interest. Ultimately, 5 articles were included in the final synthesis for the literature review.

Where data permit, meta-analysis is used with fixed or random effects models, depending on the heterogeneity between studies. Variation between studies is assessed using Cochran's Q test, I^2 statistic, and Funnel Plot. Where data are too heterogeneous or qualitative, thematic or narrative analysis is used to synthesize study results. This approach ensures that the review results are valid, transparent, and reliable in evaluating research findings.

D. Data Extraction

The key data from the selected studies were carefully extracted and organized into a structured format to facilitate analysis. This process included gathering information on study characteristics**,** such as the author, year of publication, and study design, to provide context for each piece of research. Additionally, details about the device features were collected, focusing on the types of monitoring systems used—such as temperature, heart rate, and respiratory rate sensors—along with any real-time feedback mechanisms and safety measures incorporated into the devices.

Furthermore, the review examined outcome measures to assess the effectiveness of these devices in reducing critical risks during neonatal transport, specifically targeting hypothermia, respiratory distress, and cardiovascular instability. Lastly, the data also highlighted the **limitations** faced in the development and implementation of these devices, including technical challenges, issues related to cost-effectiveness, and potential risks encountered during transport.

E. Quality Assasment

The quality of the studies included in the review was evaluated using two different tools depending on the type of study. For non-randomized studies, a modified version of the Newcastle-Ottawa Scale (NOS) was used, which assesses factors such as the selection of participants, comparability between study groups, and the measurement of outcomes. For randomized trials, the Cochrane Risk of Bias Tool was applied, which examines potential biases in the study design, such as randomization, blinding, and outcome reporting. By using these tools, we ensured that the studies included in the review were of high quality, providing reliable and valid data for the analysis.

The quality of the included studies was assessed using two different tools, tailored to the study type. For non-randomized studies, a modified version of the Newcastle-Ottawa Scale (NOS) was employed, evaluating participant selection, group comparability, and outcome measures. Randomized controlled trials (RCTs) were assessed using the Cochrane Risk of Bias Tool, which examines key aspects such as randomization, blinding, and result reporting. These tools ensured the inclusion of high-quality studies, strengthening the reliability and validity of the analysis.

For experimental studies, the Cochrane Risk of Bias Tool was utilized to assess RCTs. This tool examines crucial aspects affecting result reliability, including randomization, allocation concealment, blinding, attrition bias, and selective reporting. By identifying potential biases in study design and execution, this tool ensures the inclusion of rigorous, high-quality trials. Consequently, it enhances confidence in the meta-analysis results, as only studies with a low risk of bias contribute significantly to the overall conclusions.

F. Synthesize Results

The results were synthesized using a thematic analysis approach, which involved organizing the findings into several core categories: device innovation, the integration of real-time monitoring systems, safety enhancements, and the overall effectiveness of each tool in maintaining newborn stability during transport. Within each category, the studies were reviewed to identify common themes and

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variations. A comparative analysis was then conducted to assess the strengths and weaknesses of the different device models, highlighting differences in design, technology, and performance. This comparison allowed for a clearer understanding of which innovations showed the most promise in improving neonatal transport stability, as well as areas where further development or research is needed. By adhering to the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines, this review ensures a high level of credibility and transparency in its findings. The use of PRISMA enhances the replicability of the study by providing a well-structured and detailed methodology that future researchers can easily follow, either to build upon the findings or to verify the results through independent analysis.

This systematic approach allows for a comprehensive and reliable synthesis of the advancements in neonatal transport devices. By carefully screening and selecting only the most relevant and high-quality studies, the review guarantees that the conclusions drawn are based on robust and meaningful evidence. Furthermore, this methodical process supports the generation of insights that are not only well-founded but also valuable for guiding future research and development in the field.

3. RESULTS

The results presented below emphasize the critical elements of the studies included in this systematic review. After applying the inclusion criteria, a total of 5 studies were deemed suitable for analysis.

A. Providing resuscitation to the newborn at the maternal bedside: assessing the safety, usability and acceptability of a mobile trolley [13] .The study involved a total of 78 newborns, including 20 low-risk and 58 high-risk infants. A novel resuscitation trolley (Lifestart®) was introduced, designed to facilitate immediate bedside stabilization and resuscitation while allowing for the potential benefits of maintaining an intact umbilical cord.
   The findings demonstrated the effectiveness of the mobile trolley in neonatal resuscitation. It was successfully used in all 78 cases, proving its capability in performing various resuscitation procedures. Post-resuscitation temperature measurements revealed that 77 out of 78 infants maintained a body temperature above 36°C, indicating effective thermal management. Importantly, no adverse events were reported in relation to the trolley's use. Additionally, healthcare providers expressed a high level of acceptance and satisfaction, with the majority of physicians rating the trolley as comparable to or superior to standard resuscitation equipment. In most cases, the trolley allowed resuscitation to be performed while keeping the umbilical cord intact. However, in 18 cases, the cord length was insufficient to reach the trolley. Despite this limitation, the results strongly support the clinical use of this innovative equipment. The study concludes that the mobile resuscitation trolley provides a safe and effective solution for stabilizing preterm infants immediately after birth, potentially improving neonatal outcomes.

B. Neonatal Transport Incubators: Identification, Rating, and Vibration Damping—A New Approach to Patient Tray Stabilization [14]. This study investigated a modified neonatal transport incubator equipped with an accelerometer on the patient tray to assess and mitigate vibrations during transportation. The analysis identified dominant natural frequencies on the patient tray ranging between 8 to 10 Hz, with a vibration magnification factor of 1.60 on the tray and 3.75 on the neonatal manikin. The first mode of vibration, known as the drum mode, exhibited maximum deflection at the center of the tray, indicating potential instability. Efforts to enhance stability focused on securing the patient tray to a rigid frame, which significantly reduced vibrations. The results demonstrated a 78% reduction in Z_min, a 193% reduction in Z_max, and a 65% reduction in Z_rms, confirming the effectiveness of this modification. By minimizing excessive movement, the adjustment improves the safety and comfort of neonates during transport, potentially reducing the risk of adverse effects associated with excessive vibration. These findings highlight the importance of structural reinforcement in transport incubators to ensure a safer neonatal transport environment.

C. Rethinking ground ambulance neonatal transport [15]
   This study focused on the design and technical specifications of a specialized Type D neonatal ambulance for neonatal emergency transport services (NETS). The proposed ambulance differs significantly from the existing European Type C model, which is primarily designed for adult patients. Key features of the Type D ambulance include a compressed air cylinder, an inhaled nitric oxide (iNO) system, phototherapy equipment, a shock-absorbing stretcher, a cooling device, a refrigerator box for placenta storage, and transcutaneous gas analysis capabilities. The findings emphasize that modifying existing Type C ambulances is inadequate for neonatal care. Instead, the study advocates for the establishment of a new ambulance classification (Type D) within the European Community, underscoring the need for standardized guidelines to ensure the safe and effective transport of newborns in emergency situations.

D. Thermal conductive mattress versus routine care to reduce neonatal hypothermia during transport among low birth weight neonates: An experimental study with historical control [16].
   This study examined the effectiveness of a thermal conductive mattress (EMBRACETM) compared to routine care in preventing hypothermia among 256 low birth weight (LBW) neonates during transport. Of these, 154 were placed on a thermal conductive mattress, while 102 received routine care. The findings

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revealed that neonates transported with the thermal conductive mattress had a significantly higher mean axillary temperature upon arrival at the postnatal ward (36.6°C) compared to those in the routine care group (36.4°C, p = 0.005). While there was a reduction in the relative risk of mild and moderate neonatal hypothermia (RR = 0.59) in the mattress group, this result was not statistically significant, indicating that the clinical impact may be limited. Additionally, the number needed to treat (NNT) was 13 for mild hypothermia and 22 for moderate hypothermia, suggesting that a large number of neonates would need this intervention to prevent a single case of hypothermia. In conclusion, the thermal conductive mattress effectively increased neonatal admission temperatures, but its overall impact on preventing hypothermia was modest. While it may offer some benefits, its clinical significance remains limited.

E. Use of access port covers on transport incubators to improe thermoregulation during neonatal transport [17]

This study examined the impact of covering the snap-open access ports on a transport incubator to maintain internal temperature stability. The findings revealed that the incubator's internal temperature dropped significantly when the access port was left open, leading to greater heat loss. This effect was more pronounced in colder room temperatures, but when the port was closed or covered, the internal temperature remained stable. Statistical analysis confirmed the effectiveness of using a cover ($p < 0.05$), demonstrating its role in minimizing heat loss. As a practical solution, implementing a quick-opening access port cover can help maintain a constant temperature inside the transport incubator, reducing the risk of neonatal hypothermia. These results support the use of port covers to improve thermal management and enhance the safety of newborns during transport.

4. DISCUSSION

To initiate the discussion on the findings presented in Table 1, it is essential to highlight the diversity and depth of the studies reviewed of five selected research articles. Each article contributes unique insights into the broader topic of neonatal transport and hypothermia prevention, showcasing various methodologies and outcomes. The table provides a comparative overview, offering a detailed understanding of the experimental designs, sample populations, and key findings from each study. By examining these elements, we can identify common trends, divergences, and the overall impact of these studies on advancing neonatal care practices, particularly in relation to maintaining infant stability during transport. This comparative analysis will also help us to draw meaningful conclusions and recognize areas that require further research.

The research conducted by Thomas et al, in 2014 offers significant insights into the utilization of a mobile resuscitation trolley specifically designed for bedside use in neonatal care. This innovative approach was evaluated in a study involving 78 newborns, comprising 20 low-risk and 58 high-risk infants. The results indicated that the mobile trolley effectively facilitated resuscitation procedures for all 78 infants, underscoring its capability to perform a comprehensive range of interventions essential in emergency situations where timely action is critical [13].

A notable outcome of the study was the post-resuscitation temperature measurements, revealing that 77 out of 78 infants, maintained temperatures above 36°C. This finding highlights the trolley's effectiveness in thermal management, an essential factor in preventing hypothermia among vulnerable newborns. Importantly, no adverse events were reported in association with the trolley's use, further affirming its safety profile. Additionally, high acceptability and satisfaction among healthcare providers were evident, with most clinicians rating the trolley as comparable to or superior to traditional resuscitation equipment. Such positive feedback is crucial for the integration of new technologies into clinical practice, as clinician acceptance significantly influences the successful adoption of innovative solutions. The trolley's design also allowed for resuscitation while maintaining the integrity of the umbilical cord in most cases; however, it was noted that in 18 instances, the cord length was insufficient to reach the trolley [13].

When comparing this innovation to existing technologies, it is essential to consider previous bedside resuscitation devices, such as traditional radiant warmers and resuscitation bags. Unlike conventional methods, which may require multiple personnel for effective operation and temperature management, the mobile trolley streamlines the process by centralizing essential resuscitation tools and thermal support. Furthermore, the trolley's design addresses common challenges faced in neonatal resuscitation, such as maintaining optimal temperatures while facilitating interventions, thus representing a significant advancement in neonatal care technology. By integrating features that enhance safety, efficiency, and clinician satisfaction, the Lifestart® mobile trolley stands as a noteworthy contribution to improving outcomes in neonatal resuscitation.

The study by Sallee et al, in 2016 presents a significant advancement in neonatal transport incubator design by focusing on the identification, ranking, and attenuation of vibrations in the patient tray. This research is crucial, as mechanical vibrations can adversely affect neonates during transport, where even minor disturbances may lead to serious complications.

A key finding was the identification of dominant natural frequencies of the patient tray in the range of 8 to 10 Hz, which is critical due to the potential for resonant effects. The vibration magnification factors—1.60 at the patient tray and 3.75 at the neonatal mannequin—show that

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vibrations can be significantly amplified, leading to discomfort and harm. This aligns with previous studies, such as Wong et al in 2015, which emphasize the importance of understanding vibration dynamics in neonatal care. Further analysis revealed that the first mode of the tray, known as the drum mode, exhibited maximum deflection at the center, highlighting the need to consider neonate positioning for stability [14]; [18]. Similar findings have been reported in studies on pediatric transport systems, which noted that concentrated vibrations could affect both patient comfort and the integrity of medical equipment [19].

A significant innovation in this study was the incorporation of an accelerometer in the patient tray for real-time vibration monitoring. This allows for immediate feedback on stabilization techniques, supported by other studies emphasizing technology's role in improving neonatal outcomes [20]. By tethering the tray to a rigid frame, the researchers achieved significant vibration attenuation—78% for minimum vibrations, 193% for maximum vibrations, and 65% for root mean square vibrations—demonstrating the effectiveness of this stabilization method. The implications of these findings are substantial, suggesting that reducing harmful vibrations can enhance neonatal safety and comfort, ultimately leading to improved clinical outcomes and lower risks of complications during transport. Previous literature has also indicated that minimizing vibrations correlates with better physiological stability in neonates. Additionally, the integration of accelerometers paves the way for future innovations in neonatal transport incubator design. Real-time data acquisition may facilitate adaptive systems that adjust to transport conditions, further optimizing care for vulnerable patients. These advancements could be complemented by developing materials that absorb vibrations more effectively, akin to innovations in other high-tech medical devices [21].

In the study by Bellini et al, in 2019, the researchers critically examined the design and technical specifications of ambulances specifically tailored for neonatal emergency transport services (NETS). One of the key outcomes of this study was the detailed project design that illustrated substantial differences between the existing European Type C ambulances, which are primarily intended for adult patients, and the newly proposed Type D neonatal ambulances. The findings underscore the inadequacies of Type C ambulances when it comes to meeting the specific needs of neonatal patients, who often face critical conditions that require specialized care during transit. The proposed Type D ambulances are designed with several specialized features that enhance their functionality and safety for neonatal patients. These include: (1) Air Compressed Cylinders that essential for supplying oxygen and other gases necessary for neonatal care (adequate respiratory support during transport). (2) Inhaled Nitric Oxide (iNO) Cylinders and Delivery System which for treating neonates with pulmonary hypertension, providing targeted therapy that can improve oxygenation and overall outcomes. (3) Phototherapy Equipment that is crucial for the management of neonatal jaundice. (4) Shock-Absorbing Stretcher Support which is vital for minimizing the impact of road vibrations and sudden movements, which can jeopardize the stability of fragile neonatal patients. (5) Cooling Devices, essential for managing conditions such as hypothermia, allowing healthcare providers to regulate the infant's body temperature effectively during transport. (6) Refrigerator Box for Placenta which supports best practices in neonatal care. And (7) Transcutaneous Gas Analyzer that is needed to enables continuous monitoring of the infant's blood gases, providing real-time data that can inform clinical decisions during transport [15]; [22].

The study emphasizes the critical need for specialized neonatal ambulances that are equipped with advanced technology and equipment tailored to the unique needs of newborns. By highlighting the design differences and the essential features of Type D ambulances, the research advocates for a paradigm shift in neonatal transport services, ultimately aiming to improve the outcomes for critically ill neonates during their most vulnerable moments. This study serves as a call to action for healthcare policymakers and ambulance services to prioritize the development and implementation of these specialized transport solutions.

The research conducted by Gopalakrishnan et al, in 2021 evaluates the effectiveness of EMBRACETM in preventing hypothermia during the transport of low-birthweight (LBW) neonates. The study included a total of 256 LBW neonates, with 154 in the conductive thermal mattress group and 102 in the routine care group. This comparative study aimed to assess the impact of the conductive thermal mattress on the axillary temperature upon arrival in postnatal wards, as well as the incidence of mild and moderate hypothermia. This research is significant as hypothermia is a common and serious complication in low-birthweight neonates, particularly during transport. Maintaining normothermia is crucial for their survival and long-term health outcomes. The study provides valuable data on the effectiveness of a novel intervention (the conductive thermal mattress) in a real-world setting, which can be crucial for clinicians and healthcare policymakers [16].

Traditionally, neonatal care during transport has relied on routine practices such as using blankets, hats, and incubators. However, these methods often fail to provide adequate temperature control due to factors such as environmental conditions and the duration of transport. For instance, studies have shown that conventional warming methods can lead to inadequate temperature maintenance during transport [23]; [24]. The conductive thermal mattress represents an advancement in neonatal care technology. Previous studies on similar technologies, such as heated transport systems and warming devices, have shown promise in preventing hypothermia [25]; [26].

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However, the effectiveness of these systems often varies depending on external conditions and the specific design of the device.

This study adds to this body of literature by providing direct comparisons between a specific conductive thermal device and routine care. Despite the improvements in mean temperature, the lack of statistically significant findings regarding hypothermia incidence raises important considerations about the generalizability and applicability of the results. The findings underscore the potential benefits of using a conductive thermal mattress in preventing hypothermia during transport of LBW neonates. However, the clinical significance of the results warrants further investigation, particularly with larger sample sizes and diverse settings to better understand the efficacy and practicality of such interventions. Given the substantial NNT, it is essential for future research to focus on optimizing the use of the conductive thermal mattress and exploring additional strategies for maintaining normothermia in vulnerable neonates during transport [16].

The study conducted by Fukuyama and Arimitsu in 2023 explores an innovative approach to enhancing thermoregulation for neonates during transport. Given the vulnerability of newborns, particularly preterm infants, to hypothermia, maintaining an appropriate temperature in transport incubators is critical for preventing health complications and mortality. This research presents significant findings that support the use of access port covers as an effective intervention in transport incubators [17]. Prior to this study, several interventions aimed at improving thermoregulation during neonatal transport had been explored. Traditional methods have included the use of thermal blankets, heated mattresses, and advanced incubators with sophisticated temperature control systems [27]. For instance, heated transport systems that incorporate temperature management features are widely used; however, they can be costly and require regular maintenance [28]; [29]. In comparison, the approach of using access port covers is not only cost-effective but also easy to implement, making it accessible for a wider range of healthcare settings. Research by Kóbor et al in 2020 highlighted that conventional incubators often lose significant heat through open ports during transport, emphasizing the need for effective barriers to mitigate this heat loss [30].

Additionally, while innovations like incubators with built-in heating and cooling systems can provide effective thermoregulation, they often come with increased complexity and cost. The simplicity of snap-open access port covers offers a complementary solution that can enhance existing transport incubators without necessitating significant technological upgrades. The findings demonstrate the efficacy of this approach in minimizing heat loss and maintaining stable internal temperatures, which is vital for preventing hypothermia in vulnerable populations. By comparing this innovative solution with existing methods, it becomes evident that simple, cost-effective modifications can have a significant impact on neonatal care, thereby improving patient outcomes in a variety of healthcare settings.

This study acknowledges several limitations that may affect the interpretation of results. Language restrictions and publication bias could lead to the omission of relevant studies, necessitating careful consideration of these factors. The strict inclusion and exclusion criteria, while essential for maintaining data quality, may have limited the scope of reviewed studies. Additionally, heterogeneity among studies presents challenges in data synthesis, requiring the application of appropriate statistical strategies. By explicitly addressing these limitations in the methods section, the research enhances transparency and credibility, allowing readers to better understand the context of the findings.

5. CONCLUSION

The literature review highlights significant advancements in neonatal transport technologies and methodologies aimed at preventing hypothermia and ensuring the safety and stability of vulnerable newborns during transport. The studies analyzed provide diverse insights, revealing common trends and innovative solutions that enhance neonatal care.

In conclussion, the reviewed studies collectively underscore the importance of innovation in neonatal transport technology. By focusing on thermal regulation, vibration management, and specialized equipment, these advancements pave the way for improved clinical outcomes and enhanced safety for neonates during transport. As healthcare practices continue to advance the necessity for technological innovations in neonatal care, especially regarding transportation both within and between healthcare facilities has become increasingly evident. These insights will play a vital role in informing future research endeavors and facilitating the implementation of effective interventions aimed at reducing neonatal morbidity and mortality.

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