International Journal of Computational and Experimental Science and ENgineering (IJCESEN)

Vol. 10-No.4 (2024) pp. 4186-4194
http://www.ijcesen.com

ISSN: 2149-9144

Research Article

Roles of Biomedical Equipment Technicians, Nurses, and Health Care Assistants in Ensuring Safe Use of Infusion Pumps in Hospital Settings

Mohammed Ali Salem Albaqawi[1]*, Hamoud Bandar Alshammari[2], Ahmed Silfiq Huways Alshammari[3], Hamdan Aqeel J Alshammari[4], Mohammed Awadh N Alshammari[5], Bedour Mohammed Alruwaili[6], Alenazi, Bashayr Sulaiman H[7], Hanin Salem Mohammed Alhaddad[8], Alanazi Mona Ali M[9], Namshah Ali A Alhazmi[10], Manal Galeb Elig Alrawili[11]

[1]Health Assistant, Health Care Security, Rafha General Hospital, Northern Borders Health Cluster, Ministry of Health, Rafha, Northern Borders Region, Saudi Arabia,
* **Corresponding Author Email:** moaalbaqawı@moh.gov.sa- **ORCID:** 0000-0002-5247-7850

[2]Health Assistant Nurse, Rafha General Hospital, Northern Borders Health Cluster, Ministry of Health, Rafha, Northern Borders Region, Saudi Arabia,
Email: hbalshammari@moh.gov.sa - **ORCID:** 0000-0002-5207-1150

[3]Biomedical Equipment Maintenance Technician, Rafha General Hospital, Northern Borders Health Cluster, Ministry of Health, Rafha, Northern Borders Region, Saudi Arabia
Email: ahsialshammari@moh.gov.sa - **ORCID:** 0000-0002-5207-0150

[4]Health Assistant, Rafha General Hospital, Northern Borders Health Cluster, Ministry of Health, Rafha, Northern Borders Region, Saudi Arabia,
Email: haaqalshammarı@moh.gov.sa - **ORCID:** 0000-0002-5207-2150

[5]Health Assistant, Rafha General Hospital, Northern Borders Health Cluster, Ministry of Health, Rafha, Northern Borders Region, Saudi Arabia
Email: malshammari235@moh.gov.sa - **ORCID:** 0000-0002-5207-3150

[6]Nursing, Mansoura Primary Health Care Center, Northern Borders Health Cluster, Ministry of Health, Arar, Northern Borders Region, Saudi Arabia,
Email: Budurma@moh.gov.sa - **ORCID:** 0000-0002-5207-4150

[7]Nursing, North Medical Tower, Northern Borders Health Cluster, Ministry of Health, Arar, Northern Borders Region, Saudi Arabia
Email: bashayayra@moh.gov.sa - **ORCID:** 0000-0002-5207-5150

[8]Senior Nursing Specialist, Obstetrics and Gynecologic Nursing, East Jeddah Hospital, First Jeddah Health Cluster, Ministry of Health, Jeddah, Makkah Region, Saudi Arabia,
Email: hsalhaddad@moh.gov.sa - **ORCID:** 0000-0002-5207-6150

[9]Nursing Technician, North Medical Tower, Northern Borders Health Cluster, Ministry of Health, Arar, Northern Borders Region, Saudi Arabia,
Email: Malanazi31@moh.gov.sa- **ORCID:** 0000-0002-5207-7150

[10]Nursing Technician, Prince Abdulaziz Bin Musaad Hospital, Northern Borders Health Cluster, Ministry of Health, Arar, Northern Borders Region, Saudi Arabia,
Email: Namshah@moh.gov.sa - **ORCID:** 0000-0002-5207-8150

[11]Nursing Specialist, North Medical Tower, Northern Borders Health Cluster, Ministry of Health, Arar, Northern Borders Region, Saudi Arabia
Email: mqalrawili@moh.gov.sa - **ORCID:** 0000-0002-5207-9150

Article Info:

DOI: 10.22399/ijcesen.4935
Received : 01 March 2024
Accepted : 30 March 2024

Keywords

Infusion Pumps;
Patient Safety;
Biomedical Equipment Technician (BMET);
Nursing;
Health Care Assistant (HCA);
Smart Pump

Abstract:

The safe administration of intravenous medications via infusion pumps in hospital settings is a complex, high-stakes process that relies not on a single individual but on the synergistic collaboration of a multi-disciplinary team. Biomedical Equipment Technicians (BMETs), establish the foundational layer of safety by ensuring technical reliability through rigorous preventive maintenance, accurate repair, and the management of networked device cybersecurity. Nurses act as the clinical stewards at the point of care, applying professional judgment to verify medication orders, safely program smart pumps with their integrated dose-error reduction systems, and vigilantly monitor both the patient's physiological response and the device's alarms amidst the challenge of alarm fatigue. HCAs, through their continuous bedside presence, provide an essential extension of the care team, observing IV sites for complications, assisting with safe patient mobility, and reporting critical observations. Ultimately, ensuring zero harm from infusion therapy requires a culture of shared responsibility, mutual respect, and open communication, transforming these individual roles into a cohesive and resilient system of synergistic guardians dedicated to patient well-being.

1. Introduction

Infusion pumps have become indispensable tools in modern hospital care, representing the primary method for delivering fluids, medications, blood products, and nutritional support to patients across virtually all clinical settings. From the critical care unit administering life-saving vasopressors to the general medical ward providing antibiotics or hydration, these devices are relied upon to deliver precise volumes at controlled rates over specified durations [1]. The technology has evolved significantly from simple gravity-drip systems to sophisticated "smart" infusion pumps equipped with dose-error reduction systems, drug libraries, and extensive alarm capabilities, all designed to enhance the safety and efficacy of intravenous (IV) therapy [2]. This evolution reflects a concerted effort by manufacturers and healthcare institutions to mitigate the inherent risks associated with IV drug administration, a process known to be complex and prone to error. Despite these technological advancements, the safe use of infusion pumps is not an automatic byproduct of the device itself; rather, it is the outcome of a complex interplay between human factors, clinical workflows, and rigorous technical management [3]. The mere presence of advanced technology does not guarantee safety; it merely provides the tools with which safety can be achieved through competent and vigilant practice.The administration of intravenous medications is a high-risk, high-stakes process. Medications delivered via this route bypass the body's natural absorptive and metabolic barriers, entering the bloodstream directly and exerting their effects almost immediately. This immediacy, while therapeutically advantageous, also means that any error in dosage, rate, or medication selection can have rapid and catastrophic consequences for the patient [4]. Infusion-related errors, including wrong-rate administrations, incorrect medication selection from the pump's library, and failure to respond to occlusions or air-in-line alarms, are consistently identified as a significant source of preventable patient harm. They can lead to adverse drug events ranging from temporary discomfort and phlebitis to permanent neurological damage and death. The Institute of Medicine's seminal reports on patient safety, "To Err is Human" and "Crossing the Quality Chasm," highlighted the systemic nature of such errors and called for a fundamental redesign of healthcare processes to make them safer [5]. This call to action placed a spotlight on technologies like infusion pumps, not just as potential sources of error, but as critical components of a safer healthcare delivery system, provided they are used correctly within a supportive environment.The responsibility for ensuring that infusion pumps function as intended and are used safely does not rest on the shoulders of a single profession. Instead, it is a distributed responsibility, a shared duty that falls upon a team of professionals, each contributing unique expertise. At the heart of this safety ecosystem are three key roles: the Biomedical Equipment Technician (BMET), the Nurse, and the Health Care Assistant (HCA). These individuals operate in distinct yet deeply interconnected spheres of activity [6]. The BMET is the technical guardian, responsible for the device's physical integrity, electrical safety, and functional accuracy. The nurse is the clinical steward, applying professional judgment to program the device, select the correct therapy parameters, and monitor both the patient and the equipment for signs of trouble. The HCA, often working at the bedside, provides essential support in maintaining patient comfort and skin integrity, and in observing and reporting issues that may be precursors to a complication or device alarm. When

one of these links in the chain of safety is weak, the entire system is placed at risk. Communication breakdowns, for instance, between a nurse who notices an alarming trend and a BMET who is unaware of a recurring device issue, can create a gap through which a serious error can fall [7, 8].

2. The Biomedical Equipment Technician (BMET):

The Biomedical Equipment Technician serves as the foundational pillar upon which the safe use of all medical devices, including infusion pumps, is built. Their primary responsibility lies in the technical domain, ensuring that the equipment is physically sound, electrically safe, and functionally accurate before it ever reaches a patient's bedside. This role is a complex blend of engineering, electronics, and meticulous documentation, requiring a deep understanding of the device's internal workings and its intended clinical application. Without the rigorous and proactive work of BMETs, even the most expertly programmed pump by the most skilled nurse is a potential source of catastrophic failure.

- **Pre-Use Inspection, Preventive Maintenance, and Performance Assurance**

The journey of an infusion pump from the hospital's central equipment store to a patient's room begins with the BMET. Before a new pump is put into service, and at regular intervals throughout its operational life, it undergoes a series of rigorous inspections and tests. This process, known as incoming inspection or preventive maintenance (PM), is designed to verify that the device meets the manufacturer's specifications and all relevant safety standards. The BMET performs a detailed physical inspection, checking for damage to the casing, the integrity of the power cord and plug, the condition of the battery, and the proper latching of the pump mechanism. They then conduct a suite of functional tests, often using specialized analyzers, to confirm flow rate accuracy across a range of settings, test the functionality and sensitivity of all alarms (e.g., occlusion, air-in-line, door-open, battery low), and verify the electrical safety of the device by measuring ground wire resistance and chassis leakage current [9]. These PM inspections are not merely bureaucratic checkboxes; they are critical interventions designed to identify and correct latent equipment failures before they can contribute to a clinical error. A pump with a slightly inaccurate flow rate, for example, could lead to a significant under- or over-infusion over a 24-hour period, a problem that would only be detectable through the precise measurements of a BMET's test equipment [10]. This proactive approach to maintenance is the first and most crucial line of defense against technology-induced harm.

- **Troubleshooting, Repair, and Root Cause Analysis of Failures**

When a pump is reported as malfunctioning, either through a formal work order or a verbal report from clinical staff, the BMET transitions into a diagnostic and remedial role. This involves troubleshooting the reported problem, which requires a systematic approach to isolate the fault. The BMET must interpret error codes, use schematics and service manuals, and employ diagnostic tools like multimeters and oscilloscopes to pinpoint the failed component, whether it be a worn-out motor, a faulty sensor, a cracked circuit board, or a software glitch. Once the root cause is identified, the technician performs the necessary repair, which may involve replacing a component, recalibrating a sensor, or updating the device's software. A critical, and often underappreciated, aspect of this repair process is the conduct of a thorough root cause analysis [11]. When faced with a recurring issue, such as repeated "occlusion" alarms on a particular model of pump, a skilled BMET does not simply fix the immediate symptom. Instead, they investigate the underlying cause. Is it a true clinical occlusion? Is there a design flaw in the pump's pressure sensor? Is it being used with incompatible administration sets? By asking these deeper questions and documenting their findings, BMETs provide invaluable feedback to hospital leadership and even to manufacturers, driving improvements in both device design and hospital purchasing decisions. This investigative function elevates their role from simple repair technicians to active participants in the hospital's quality improvement and risk management processes [12].

- **Technology Management and Cybersecurity**

In the contemporary hospital environment, infusion pumps are no longer isolated devices; they are often part of a vast network, wirelessly connected to the electronic health record (EHR) and pharmacy systems as part of a smart pump ecosystem. This interoperability, while offering immense benefits in terms of data capture, automated documentation, and dose-error reduction, also introduces new vulnerabilities. The BMET's role has expanded to include the management of this technology infrastructure. They are responsible for ensuring that pumps are correctly configured on the wireless network, that drug libraries are successfully and consistently downloaded to every pump, and that data from the pumps flows accurately into the hospital's information systems [13]. This is a complex task that requires collaboration with the

hospital's information technology (IT) department. Furthermore, as networked devices, infusion pumps become potential entry points for cyberattacks. BMETs are now on the front lines of medical device cybersecurity, working with IT to ensure that pumps have the latest security patches, are protected by firewalls, and are monitored for unusual network activity that could indicate a breach [14]. A failure in this domain could have dire consequences, potentially allowing a malicious actor to alter pump settings remotely, leading to patient harm on a wide scale. Thus, the BMET's role in technology management is now an essential component of both patient safety and hospital security.

- **Collaboration and Communication with Clinical Staff**

The effectiveness of a BMET is not solely determined by their technical acumen; it is equally dependent on their ability to communicate and collaborate effectively with nurses and other clinical staff. When a nurse reports a pump problem, the quality of the information they provide is critical to a swift and accurate resolution. Conversely, when a BMET completes a repair or a PM, they have a responsibility to clearly communicate the device's status to the clinical team. This often involves physically tagging the pump as "safe for use" and, in the case of a resolved issue, providing a brief explanation to the nursing staff to restore their confidence in the device. This two-way communication builds a crucial bridge between the technical and clinical worlds [15]. Regular interdisciplinary meetings, where BMETs can share data on pump performance and common alarm trends, and nurses can provide feedback on usability issues or design challenges they encounter, are a hallmark of a high-reliability organization. This collaborative dialogue ensures that the technical management of the pumps is aligned with the practical realities of clinical use, fostering a shared sense of ownership over patient safety and preventing the emergence of a "blame culture" when things go wrong [16]. In this model, the BMET is not a distant repair person, but a trusted partner in the clinical environment.

3. The Nurse: The Clinical Steward at the Point of Care

While the BMET ensures the pump is safe to use, the nurse is the professional who makes the critical decisions to use it safely at the point of care. The nurse acts as the final, and perhaps most important, check in the medication administration process, translating a physician's order into a precise therapy delivered to a specific patient. This role demands not only a deep understanding of pharmacology and human physiology but also a high level of proficiency with the infusion pump technology itself. The nurse is the clinical steward, responsible for programming the device, verifying its accuracy, monitoring its function, and assessing the patient's response to the therapy.

- **Verification of the "Five Rights" and Smart Pump Programming**

The foundation of safe medication administration rests on the principle of the "Five Rights": right patient, right drug, right dose, right route, and right time. For infusion pump therapy, this process begins long before the pump is touched. The nurse must first verify the medication order against the patient's identity, allergies, and clinical condition. They must then select the correct IV fluid or medication, checking its label against the order and noting its expiration date. The next critical step is the selection and inspection of the correct administration set, ensuring it is compatible with the specific pump model and is free from defects [17]. Only after these meticulous checks does the nurse approach the pump. Modern smart pumps are designed to support this process. The nurse typically begins by scanning the patient's wristband, their own ID badge, the medication, and the pump itself, a process known as barcode-assisted medication administration (BCMA). This creates an electronic "eMAR" record and ensures that all elements are correctly matched. The nurse then selects the appropriate medication from the pump's pre-programmed drug library, which then prompts for the dose and rate. The pump's dose-error reduction system provides a critical safety net, alerting the nurse if the programmed dose falls outside of predetermined "soft" or "hard" limits [18]. A soft limit generates a warning but can be overridden with justification, while a hard limit cannot be overridden, preventing a potentially fatal dose from being infused. The nurse's role is to understand these alerts, to investigate why a dose might be outside the normal range, and to use their clinical judgment to either accept the warning and correct the entry, or, in the case of a soft limit, to carefully override it with a clear rationale, such as a specific physician's order for an unusual dosage [19].

- **Patient Assessment, Monitoring, and Alarm Response**

Once the infusion is running, the nurse's role shifts from programmer to vigilant monitor. This involves a dual focus on both the patient and the pump. The nurse must regularly assess the patient's physiological response to the therapy, monitoring vital signs, level of consciousness, and any signs of adverse effects. They must also assess the IV site

itself for signs of complications such as infiltration (leakage of fluid into surrounding tissue), extravasation (leakage of a vesicant drug that can cause tissue damage), phlebitis (inflammation of the vein), or infection [20]. These clinical assessments are as crucial to safety as the pump's own technical alarms. Simultaneously, the nurse must attend to the pump's alarms. The modern clinical environment is notorious for "alarm fatigue," a phenomenon where the high frequency of non-actionable or false alarms desensitizes caregivers, leading to delayed or missed responses to critical alerts [21]. Infusion pumps contribute significantly to this cacophony, with common alarms for occlusions, air in line, low battery, and infusion complete. The nurse must be able to quickly differentiate between these alarms, prioritize them, and respond appropriately. A "low battery" alarm may simply require plugging the pump in, while an "air in line" alarm requires immediate assessment to rule out a true air embolism risk. An "occlusion" alarm requires the nurse to trace the line from the pump to the patient to find the kink, closed clamp, or other blockage. A delayed response to a true downstream occlusion, for instance, could lead to a sudden bolus of medication being delivered to the patient when the occlusion is released [22]. Therefore, the nurse's ability to manage alarms effectively is a direct determinant of patient safety.

- **Education of Patients and Families**

An often-overlooked but vital aspect of the nurse's role is the education of the patient and their family. For a patient, being attached to an infusion pump can be an anxiety-provoking experience. The machine beeps, it restricts movement, and its purpose may not be fully understood. Nurses play a key role in demystifying the technology and empowering the patient to be a partner in their own safety. This education can include explaining what medication is being given and why, what the pump's alarms mean, and what the patient should do if an alarm sounds (e.g., call for help, not try to silence it themselves) [23]. Nurses can also instruct patients and families on what to observe and report, such as pain, swelling, or redness at the IV site. When a patient is ambulatory, the nurse teaches them how to move safely with the pump on its pole, ensuring they do not trip over the tubing or pull the IV line out. By transforming the patient from a passive recipient of therapy into an informed observer, the nurse extends the "safety net" beyond their own direct supervision. An educated patient who reports a strange beep or a new pain at the IV site can be the trigger that prevents a minor issue from escalating into a serious complication.

- **Documentation and Communication within the Care Team**

The nurse's role as a steward of safety is not complete without meticulous documentation and clear communication. All aspects of the infusion process must be accurately recorded in the patient's medical record. This includes the verification of the five rights, the settings programmed into the pump (rate, volume to be infused), the patient's response to the therapy, the condition of the IV site, and any alarms or interventions that occurred [24]. In hospitals with fully integrated smart pump-EHR systems, much of this data, such as the programmed rate and delivered volume, can be automatically documented, reducing the documentation burden and improving accuracy. However, the nurse's narrative notes remain essential for capturing clinical observations that cannot be automated, such as the patient's level of pain or the appearance of the IV site. Furthermore, the nurse serves as the central communicator about the infusion therapy. They receive the initial order from the physician or pharmacist, they communicate any issues or changes in the patient's condition back to the provider, and they provide a hand-off report to the oncoming nurse at shift change. This hand-off is a critical moment for patient safety, requiring a structured and complete transfer of information about the infusion, including the type of medication, the current rate, the volume infused, the status of the IV site, and any planned changes [25]. A breakdown in this communication can lead to gaps in care, such as a new nurse unknowingly continuing an infusion that was supposed to be discontinued, or failing to recognize a deteriorating IV site.

4. The Health Care Assistant (HCA):

The Health Care Assistant, also known as a nursing assistant or patient care technician, is a vital member of the healthcare team whose contributions to infusion pump safety are often under-recognized. While they do not program the pump or administer medications, their constant presence at the bedside positions them as the "attentive eyes and hands" of the team. They provide essential supportive care that directly impacts the success and safety of the infusion therapy, and they serve as an invaluable source of real-time information about the patient and the equipment. Their role is one of vigilant observation and practical support, bridging the gap between the nurse's clinical interventions and the patient's daily experience of being on an IV.

- **Monitoring IV Site and Patient Comfort**

The HCA's most critical contribution to infusion pump safety is their role in the ongoing assessment

of the patient and the IV site. During routine care activities such as bathing, turning, feeding, or assisting with ambulation, the HCA has repeated opportunities to observe the infusion. They are trained to look for visible signs of complications. This includes checking the IV insertion site for redness, swelling, pallor, or leakage, which could indicate infiltration or phlebitis. They also check the tubing to ensure it is not kinked, clamped, or dangling where it could be caught on bedrails or furniture. They can assess the patient's comfort by asking about pain, burning, or tenderness at the site [26]. The HCA is also in a prime position to notice if the patient is manipulating the pump or tubing, a particular risk in elderly, confused, or pediatric patients. If an HCA observes any of these signs, they have a clear and immediate responsibility to report their findings to the nurse. This early warning system can be critical. A small amount of swelling reported by an HCA during a morning bath can allow a nurse to intervene and restart an IV in a new site long before the pump's occlusion alarm would have sounded, preventing patient discomfort and the potential for more serious tissue damage. In this way, the HCA acts as a continuous, low-tech monitoring system that complements the high-tech alarms of the pump.

- **Assisting with Activities of Daily Living and Mobility**

Being tethered to an infusion pump and pole can significantly impact a patient's ability to perform basic activities of daily living (ADLs) and to mobilize safely. The HCA is the primary professional who assists patients with these tasks, and their skill in doing so is essential for preventing therapy-related incidents. When helping a patient to the bathroom, the HCA must know how to safely manage the IV pole, ensuring the pump remains upright and that the tubing has enough slack to move freely without being pulled taut. They must guide the patient carefully to avoid tripping over the pole's base or the tubing. When the patient is in bed, the HCA must be mindful of the tubing when repositioning the patient, ensuring it does not become trapped under the patient's body, which could cause a pressure injury or occlude the flow. When changing linens, they must move the tubing and pump safely out of the way [27]. These seemingly simple tasks require training and awareness. An improper move by an HCA could inadvertently dislodge the IV catheter, causing it to fail and requiring a painful reinsertion. More seriously, it could lead to the pump being pulled off its pole and onto the floor, potentially damaging the device or, worse, causing it to fall on the patient. The HCA's competence in these basic care activities is therefore a direct contributor to the continuity and safety of the infusion.

- **Basic Equipment Checks and Reporting**

While HCAs are not trained to troubleshoot or repair equipment, they can perform basic, non-invasive checks on the pump and its accessories. They can verify that the pump is plugged into an electrical outlet and that the outlet appears to be working. They can note if the pump is beeping and what the displayed message says (e.g., "occlusion," "air in line," "low battery"). They can check that the IV bag hanging from the pole still contains fluid and is not empty. They can also observe the drip chamber to see if fluid is dripping as expected [28]. This level of observation allows them to act as a second set of eyes for the nurse. If an HCA notices that an IV bag is nearly empty, they can alert the nurse to prepare the next bag, preventing the pump from running dry and alarming. If they hear an unfamiliar or persistent alarm, they can report it immediately, prompting the nurse to investigate before the situation escalates. Their role is not to interpret the alarm's clinical significance, but to be a reliable reporter of its occurrence. This simple function helps to ensure that alarms are not missed, especially in a busy ward where a nurse may be attending to multiple patients.

- **Communication and Teamwork**

The effectiveness of the HCA in this supportive role is entirely dependent on a culture of open communication and teamwork. There must be a clear and respected hierarchy of reporting: the HCA reports all observations to the nurse, who then assesses the situation and determines the appropriate clinical or technical intervention. For this system to work, the nurse must value and respect the HCA's input, treating their reports not as interruptions, but as valuable contributions to patient care. Conversely, the HCA must feel empowered and psychologically safe to speak up when they see something concerning, without fear of being dismissed or reprimanded. This requires a shared mental model of the patient's care plan. The nurse should inform the HCA of the type of infusion the patient is receiving and any specific things to watch for. For example, if a patient is on a vesicant chemotherapy drug, the nurse will emphasize the critical importance of immediately reporting any signs of pain or swelling at the IV site [29]. This shared understanding transforms the HCA from a task-oriented worker into a proactive member of the safety team, whose observations are a critical component of the system of checks and balances that protects the patient from infusion-related harm.

5. The Critical Interface: Where Roles Converge for Patient Safety

While the distinct roles of BMETs, nurses, and HCAs have been examined separately, the true strength of a patient safety system lies in the seamless integration of their efforts. Patient safety is not a summation of individual actions, but a product of their interaction. The most critical moments for preventing errors occur at the interfaces between these professional domains. When these interfaces are characterized by clear communication, mutual respect, and shared purpose, the system is resilient. When they are weak or fractured, it becomes vulnerable to failure. The safe use of infusion pumps, therefore, depends on the quality of collaboration among these three core groups.

- **The BMET-Nurse Interface: From Device Repair to Clinical Partnership**

The relationship between the BMET and the nurse is the classic interface between the technical and clinical worlds. A functional partnership here is essential. When a nurse encounters a pump they suspect is malfunctioning, their ability to articulate the problem clearly to the BMET is the first step in a successful resolution. Instead of simply saying "the pump is broken," a well-trained nurse can provide specifics: "The pump alarmed for 'air in line' three times in the last hour, even though I've thoroughly primed the tubing each time." This level of detail provides the BMET with a valuable clue, pointing them toward a potential intermittent sensor issue rather than a general fault. On the other side, when the BMET returns the pump to service, a brief, friendly explanation of what was wrong and what was fixed can go a long way. It builds the nurse's trust in both the device and the technician's competence. This collaborative dynamic can be formalized through processes like "technology rounds," where a BMET periodically visits clinical units to check in with nurses, answer questions about new equipment, and proactively address any minor issues before they become major problems [30]. This proactive engagement breaks down the "us versus them" mentality that can sometimes exist between departments and fosters a shared sense of responsibility. In this environment, a nurse is more likely to report a minor issue, and a BMET is more likely to understand the clinical context in which the device operates, leading to better problem-solving and a safer environment for patients.

- **The Nurse-HCA Interface: The Communication Loop at the Bedside**

The interface between the nurse and the HCA is the most dynamic and continuous, occurring constantly at the patient's bedside. The safety of the infusion relies on a well-functioning communication loop between these two roles. The nurse initiates the loop by providing clear, specific instructions and information to the HCA at the start of their shift. This includes detailing which patients have IV infusions, the type of medication being given, and, most importantly, what specific observations the HCA should report immediately. The HCA then closes the loop by providing timely and accurate feedback on their observations. This is not a one-time transaction but a continuous dialogue. An HCA might report, "Mr. Smith's IV site looks a little puffy to me," and the nurse might respond, "Thank you, I will go and assess it right now." Later, the nurse might close their own loop by reporting back to the HCA, "You were right, the IV had infiltrated. I've stopped it and will be starting a new one." This simple acknowledgment reinforces the HCA's value and encourages continued vigilance. Breakdowns in this loop are a major source of preventable harm. If an HCA reports a concern that the nurse ignores or forgets to follow up on, and the patient subsequently develops a significant infiltration, the failure is systemic—a failure of communication, teamwork, and shared responsibility [31]. A high-functioning nurse-HCA team operates almost as a single cognitive unit, with the HCA extending the nurse's sensory reach, and the nurse providing the clinical judgment to act on the information gathered.

- **The BMET-HCA Interface: An Untapped Opportunity for Safety**

The interface between the BMET and the HCA is often the least developed, yet it holds significant untapped potential for improving safety. In the traditional model, these two professionals rarely interact directly. The HCA reports an equipment issue to the nurse, who then contacts the BMET. This indirect communication can lead to delays and loss of information. However, forward-thinking hospitals are beginning to recognize the value of a more direct connection. HCAs spend more time with patients and their equipment than almost any other professional. They are the ones who move the pumps, who see them get bumped into walls, and who hear them beep throughout the night. If given basic training on what types of physical damage to look for (e.g., cracks in the casing, frayed cords, sticky keypads) and a simple, direct way to report these findings to the BMET department, they could become an invaluable source of real-world device performance data [32]. This could be as simple as a dedicated logbook in the unit or a quick-report feature in the hospital's communication app. By creating a direct channel between the HCA and the BMET, the hospital empowers the HCA, speeds up the reporting of physical defects, and provides the

BMET with crucial information about how the equipment is holding up under the stresses of daily use. This closes another loop in the safety system, ensuring that a pump with a cracked casing that could harbor bacteria, or a frayed cord that poses an electrical risk, is removed from service promptly, not just at the next scheduled PM [33].

6. Conclusion:

The modern infusion pump, for all its technological sophistication, remains a tool whose safety is entirely dependent on the humans who interact with it. It is not, and can never be, a fully autonomous, error-proof device. Its safe operation in the complex and dynamic environment of a hospital is the product of a carefully orchestrated collaboration among a diverse team of healthcare professionals. The Biomedical Equipment Technician, the Nurse, and the Health Care Assistant each hold a distinct and indispensable piece of the patient safety puzzle. The BMET provides the foundation of technical reliability, ensuring the pump is accurate, safe, and secure. The nurse acts as the clinical steward, applying expert judgment to translate orders into safe therapy and monitoring its effects. The HCA serves as the attentive eyes and hands at the bedside, providing continuous observation and supportive care that protects the patient and the integrity of the infusion.The analysis presented here has demonstrated that these roles are not isolated silos but deeply interconnected components of a single system. A failure in the technical domain, such as an undetected calibration error, can undermine the best clinical practice. A failure in the clinical domain, such as a programming mistake driven by alarm fatigue, can render a perfectly functional pump dangerous. A failure in the supportive care domain, such as an HCA's unobserved report of a reddened IV site, can allow a minor complication to escalate into a major one. The strength of the safety net, therefore, is determined not by the strength of its individual threads, but by the integrity of the weave that binds them together.This interconnectedness places a profound responsibility on healthcare institutions to foster a culture of safety that transcends professional boundaries. This culture must be built on a foundation of mutual respect, open communication, and shared purpose. It requires investment in robust initial and continuing education for all three roles, not just on the technical aspects of the pump, but on the roles and responsibilities of their colleagues. It requires the creation of formal and informal channels for communication—from bedside handoffs to interdisciplinary safety huddles to direct reporting lines between HCAs and BMETs.

Author Statements:

- **Ethical approval:** The conducted research is not related to either human or animal use.
- **Conflict of interest:** The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper
- **Acknowledgement:** The authors declare that they have nobody or no-company to acknowledge.
- **Author contributions:** The authors declare that they have equal right on this paper.
- **Funding information:** The authors declare that there is no funding to be acknowledged.
- **Data availability statement:** The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.
- **Use of AI Tools:** The author(s) declare that no generative AI or AI-assisted technologies were used in the writing process of this manuscript.

References

[1] Giuliano K. Intravenous smart pumps: usability issues, intravenous medication administration error, and patient safety. Crit Care Nurs Clin N Am. 2018;30(2):215–224.

[2] Batista E, Ferreira MdC, Furtado A, Sousa JAe. New EMPIR project - Metrology for Drug Delivery, the role of IPQ. In: 2019 IEEE international symposium on medical measurements and applications (MeMeA). 2019; pp. 1–5.

[3] Lopes A. Avaliação de desempenho para seleção de bombas de infusão destinadas a terapias com fármacos de meia-vida curta, janela terapêutica estreita e baixas vazões. PhD thesis, Universidade Federal do Rio de Janeiro. 2012

[4] Golpaygani A, Movahedi M, Reza M, Hassani K. A study on performance and safety test of infusion pump devices. Biomed Res-India. 2017;28(12):5179–5181.

[5] Johnson S. Smart pump implementation to meet anticipated surge needs during the COVID-19 pandemic. Nova scotia health. Can J Nurs Informatics. 2021; 16(1)

[6] Soares, F., Vieira, A., Soares, M., Sant'anna, M., Nascentes, R., Bossu, C. Peristaltic Pump And Detection System Controlled By An Arduino Open Source Hardware Developed And Designed For Application In A Flow. Quim Nova. 2018; 41(10), 1196–1199.

[7] Button V. Equipamentos médico-hospitalares e o gerenciamento da manutenção. In: Série F. Comunicação e Educação em Saúde. Brasília DF, Capítulo 8. Dispositivos de Infusão, Brasília - DF. 2002; pp. 303–305

[8] Samaranayake N, Cheung S, Chui W, Cheung B. Technology-related medication errors in a tertiary hospital: a 5-year analysis of reported medication incidents. Int J Med Informatics. 2012;81(12):828–833.

[9] Cauchi A, Thimbleby H, Oladimeji P, Harrison M. Using medical device logs for improving medical device design. In: 2013 IEEE international conference on healthcare informatics. 2013; pp. 56–65.

[10] Blake J, Giuliano K. Flow accuracy of IV smart pumps outside of patient rooms during COVID-19. AACN Adv Crit Care. 2020;31(4):357–363.

[11] Reis R, Milagre S, Pereira A, Souza D, Sá A. Análise metrológica e incertezas de medição como auxílio na avaliação de qualidade de bombas de infusão. In: X Conferência de Estudos em Engenharia Elétrica. 2012; pp. 1–5

[12] Junior AD. Estudo metrológico volumétrico de bombas de infusão peristálticas lineares. PhD thesis, Universidade Tecnológica Federal do Paraná. 2016

[13] Batista E, Sousa JA, Cardoso S, Silvério V. Experimental testing for metrological traceability and accuracy of liquid microflows and microfluidics. Flow Meas Instrum. 2020;71:101691.

[14] Taghipour S, Banjevic D. Trend analysis of the power law process with censored data. In: 2011 proceedings - annual reliability and maintainability symposium. 2011; pp. 1–6.

[15] King P, Fries R, Johnson A. Design of biomedical devices and systems. 4th edition. CRC Press; 2014. pp. 23–38.

[16] Enes S, Opitz S, Faro A, Pedreira M. Phlebitis associated with peripheral intravenous catheters in adults admitted to hospital in the Western Brazilian Amazon. J Sch Nurs USP. 2016;50(2):261–269.

[17] Shah A, Xu J, Friedman S, Puskas J, Bhatt H, Yimen M. Comparative analysis of intravenous pumps relocation for critically ill isolated COVID-19 patients from bedside to outside the patient room. J Intensive Care Med. 2021;36(6):719–725.

[18] Rocha P, Rocha M, Andrade I, Mota M. Assessment of nurses' knowledge about the importance of continuous infusion of catecholamines in intensive care unit. Revista Mineira de Enfermagem. 2010;14(4):459–464.

[19] Baeckert M, Batliner M, Grass B, Buehler PK, Daners MS, Meboldt M, Weiss M. Performance of modern syringe infusion pump assemblies at low infusion rates in the perioperative setting. British J Anaesth. 2020;124(2):173–182.

[20] Etelvino M, Pereira M, Barreiro-Filho R. Infusion pump risk management. (2019). Gerenciamento de risco em bombas de infusão. Vigil Sanit Debate, Rio De Janeiro. 2019;7(4):61–66.

[21] Batista E, Sousa JA, Álvares M, Afonso J, Martins RF. Development of an experimental setup for micro flow measurement using the front tracking method. Meas Sens. 2021;18:100152.

[22] Manrique-Rodríguez S, Sánchez-Galindo AC, López-Herce J, Calleja-Hernández MÁ, Iglesias-Peinado I, Carrillo-Álvarez Á, Sáez MS, Fernández-Llamazares CM. Risks in the implementation and use of smart pumps in a pediatric intensive care unit: application of the failure mode and effects analysis. Int J Technol Assess Health Care. 2014;30(2):210–217.

[23] Lee SH, Kang W, Chun S. Dynamic behavior analysis of drug delivery devices using a dynamic gravimetric method. Flow Meas Instrum. 2018;62:105–112.

[24] Felipe MDAA, Latour JM, Peterlini MAS, Pedreira MDLG. Placement of syringe infusion pumps and solution density can impact infusion performance: an experimental study. J Neonatal Nurs. 2020;26(3):149–151.

[25] Peterfreund R, Philip J. Critical parameters in drug delivery by intravenous infusion. Expert Opin Drug Deliv. 2013;10(8):1095–1108.

[26] Dychter S, Gold D, Carson D, Haller M. Intravenous therapy: a review of complications and economic considerations of peripheral access. Art Sci Infus Nurs. 2012;92121:84–91.

[27] Blancher M, Repellin M, Maignan M, Clape C, Perrin A, Labarere J, Debaty G, Viglino D. Accuracy of low-weight versus standard syringe infusion pump devices depending on altitude. Scand J Trauma Resusc Emerg Med. 2019.

[28] Hedge V. Reliability in medical device industry. Handbook of performability engineering. London: Springer; 2008. pp. 997–1009.

[29] Methley A, Campbell S, Chew-Graham C, McNally R, Cheraghi-Sohi S. PICOS and SPIDER: a comparison study of specificity and sensitivity in three search tools for qualitative systematic reviews. BMC Health Serv Res. 2014;14(1):2.

[30] Liu Z, Zhong X-r, Lu M-h. Reliability analysis and typical failure case study of the domestic medical equipment. In: international conference on quality, reliability, risk, maintenance and safety engineering (QR2MSE 2019), Hunan, China. 2019; pp. 532–537

[31] Magrupova MT, Matyakubova PM, Magrupov TM, Abdihalikov SP. Methods for increasing and assessing reliability of medical equipment. 2020 International conference on information science and communications technologies, ICISCT 2020. 2020; 2020–2022.

[32] Hagle M, Snyder K, Janicek K, Bell K, Dietz B, Gundacker N, Kinter A, Severson A. Using a patient safety analysis to guide infusion therapy for patients with COVID-19. J Infus Nurs. 2021;44(5):259.

[33] Markevičius V, Navikas D. Reliability of syringe infusion pump data channel. Proceedings of the international conference on information technology interfaces. 2008; ITI, 733–738.