Damascus university journal
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مجلة جامعة دمشق للعلوم ....
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Designing and Implementing a Digital Checklist System for Evaluating Infection Control Practices in Intensive Care Units

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ABSTRACT:

The primary objective of this research was to evaluate infection control practices (ICP) within ICU settings by utilizing a specially designed digital checklist system. The intention was to provide an effective and practical tool for reducing the incidence of Healthcare-Associated Infections (HAI). The study involved assessing the implementation of infection control protocols and measures based on the Infection Control Assessment Tool (ICAT). Through observations and data collection, various aspects of infection control practices were examined, and areas for improvement were identified. The effectiveness of the checklist system as a monitoring and enhancement tool was also evaluated. The system was tested and implemented in two different Medical ICUs in different two private hospitals in Lattakia, Syria in February 2024, the findings of the study revealed both strengths and weaknesses in the current practices employed and the overall scores obtained by both ICUs were above 75% for five of the eight modules. The checklist system demonstrated its value in capturing data and facilitating real-time decision-making. However, some customization was necessary to align it with the specific workflow of local ICUs.

Received:
Accepted:

الملخص:

يهدف البحث لتقييم ممارسات السيطرة والتحكم بالعدوى في وحدات العناية المركزة باستخدام نظام قائمة فحص رقمية. عمل البحث على توفير أداة فعالة وعملية للحد من حدوث أحداث العدوى المرتبطة بالرعاية الصحية. تضمنت الدراسة تقييم تنفيذ بروتوكولات وتدابير التحكم والسيطرة على العدوى بناءً على أداة تقييم إجراءات السيطرة والتحكم بالعدوى (ICAT) من خلال الملاحظات وجمع البيانات وفحص جوانب مختلفة لممارسات السيطرة على العدوى وتحديد المجالات التي تحتاج إلى تحسين. تم تقييم فعالية نظام قائمة الفحص الرقمية كأداة لمراقبة وتعزيز ممارسات السيطرة على العدوى واختباره عن طريق تطبيقه في وحدتي عناية مركز في مستشفيين خاصين في اللاذقية، سوريا في فبراير ٢٠٢٤. كشفت نتائج الدراسة عن نقاط قوة وضعف في الممارسات الحالية المستخدمة حيث حققت الوحدتان أكثر من ٧٥٪ من إجمالي النقاط الممكنة في ٥ وحدات من أصل ثمانية. أثبت نظام قائمة الفحص الرقمية قيمته في جمع البيانات وتسهيل اتخاذ القرار في الوقت الفعلي. ومع ذلك، كان هناك حاجة إلى بعض التخصيص لمواءمته مع سير العمل الخاص بوحدات العناية المركزة المحلية.

Keywords: Infection Control Practices (ICP), Healthcare-Associated Infection (HAI), Infection Control Assessment Tool (ICAT)

1. Introduction:

The COVID-19 pandemic, along with several other diseases that have recently spread, has clearly demonstrated the extent to which infections can spread among patients, visitors, and medical staff in a healthcare environment that does not have adequate infection prevention and control procedures. Infections associated with healthcare practices or hospital-acquired infections are among the most common events that occur in the context of providing health services (Haque et al., 2018). This type of infection harms patients, visitors, and workers in the health care institution, which subsequently constitutes an extra burden on health systems, including additional costs associated with providing health care to them (Khan et al., 2017). According to estimates by the World Health Organization, out of every 100 patients in intensive care hospitals, 7 of them in high-income countries and 15 in low-income countries will develop at least one infection associated with the health service provided to them during their hospital stay. Also, on average, one person out of every ten that are infected as a result of the infection they acquired will die (WHO, 2022). Patients in intensive care units (ICU) are often the most susceptible to this type of infection, as approximately 50% of them can be infected during their stay (Bagheri Nejad et al., 2011). This problem appears in intensive care units due to the long working hours for the medical staff and poor compliance with infection prevention and control procedures and protocols, in addition to the weak immunity of patients as a result of their health condition, as well as the length of their stay inside the unit, in addition to their contact and use of many procedures such as mechanical ventilation and different types of catheters (Maki et al., 2008). Although taking effective steps to prevent infection in intensive care units is difficult and demanding, especially in resource-limited or developing countries, where data related to this context are scarce, establishing clear and appropriate policies and procedures to control and prevent infection is the main key to reducing the significant impact of this type of infection. Many international organizations have developed standards for preventing and controlling the transmission of infection between patients and health workers and evaluation of these procedures. One of the most prominent methods and tools that have been designed is the Infection Control Assessment Tool (ICAT). Which is used to facilitate the identification, control, and prevention of hospital infections through an evaluation system that is easy to manage and record its results. It also highlights areas of interest and suggests economic improvements within hospitals (South African Department of Health, 2014).

Research objective

This study aims to Design a computer system based on ICAT used to evaluate the level of infection control procedures in ICU units to ensure a good level of these procedures, clarify the areas that need improvement, and suggest economic solutions that are applicable in low-resource health care environments.

Research Importance

Controlling infections associated with healthcare practices is a major goal for all health sector institutions because of the danger it poses to the lives of patients, visitors, and health staff. Therefore, especially in developing countries with low-resource health sectors, this study will present a computer system that can greatly help in identifying gaps and weaknesses. In infection control and prevention practices, it gives suggestions and methods for improvement that are economically appropriate, which contributes to reducing the levels of this type of infection and improving the level of quality of the health service that is provided. It will also form a cornerstone in building an electronic database to obtain data that is related to infection control regularly.

2. Literature Review

ICAT has been widely used in many developing countries and has proven its effectiveness. The study by (Gonzalez et al, 2015), which focused on the field of infection prevention and control in healthcare institutions in North America, concluded that some validated tools such as ICAT are possible options for use. (Huskins et al, 2011) emphasized that ICAT is a simple and practical tool to improve infection control in low-resource healthcare facilities and is widely implementable to reduce healthcare-associated infections, while (Ulfah, S.M., 2017) aimed to find out whether (ICAT) could be used in primary healthcare facilities to assess infection risks and concluded that all modules of the ICAT tools can be used to assess infection risks in primary care facilities with minor modifications.(Faizan, M et al ,2020) used the Infection Control Assessment Tool (ICAT) to improve infection prevention and control (IPC) standards in Children Hospital Lahore (CHL), and concluded that Implementing a collaborative improvement strategy improved IPC standards in the designated center, which can be easily replicated in other pediatric oncology centers in lower- and middle-income countries.(Mahomed et al., 2017) focused on evaluating infection control in Six public and five private adult ICUs in South Africa. Seven modules from the ICAT were administered including ICU, hand hygiene, isolation, and standard precautions. (Abed, Neveen & Eldesouky, Rasha, 2020) used ICAT to evaluate the extent to which nurses in neonatal care units adhered only to the part related to hand hygiene practices and to identify areas for improvement. The study (Ekanga, 2019) included an assessment of levels of compliance in healthcare institutions in Cameroon with the guidelines and recommendations of stakeholders regarding the control and prevention of nosocomial infections using (ICAT).

Our research fundamentally distinguishes itself from previous studies and investigations that relied on the traditional manual approach, encompassing either the entire tool or certain sections of it. In contrast, our study focused on developing a computer program specifically designed to streamline and automate the assessment of infection control procedures within ICUs. This program was tailored to the unique circumstances of healthcare institutions in the Syrian Arab Republic, aiming to assist healthcare providers in gauging the effectiveness of their infection control practices and addressing any deficiencies. Additionally, it aims to contribute to the creation of an electronic database that stores the data generated during these assessments. This database can prove invaluable in monitoring performance over time and making comparisons between different healthcare providers..

3. Research Methodology

The Research methodology was based on the following steps:

- Problem Definition and Study: The study focused on investigating infections related to healthcare practices, including their definition, types, and reasons for their spread, in order to clearly develop the checklist.
- Introduction to the Infection Control Assessment Tool (ICAT): Contents, Mechanism, and Purpose: The ICAT which is the cornerstone of the system, a tool for evaluating infection control practices, was introduced. Its contents, mechanism, and purpose of application were explained
- Practical Design and System Architecture: components development such as the Checklist, user interface, and reporting functionalities.
- Implementation and testing of the digital Checklist System: Evaluate the implementation of infection control practices within an actual ICU setting and verify the operational effectiveness of the program.

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Healthcare-associated infection (HAI)

A nosocomial infection, also referred to as healthcare-associated infection (HAI), is an infection acquired during the process of receiving healthcare that was not present during the time of admission (Sikora, A., & Zahra, F., 2023). They may occur in different areas of health care delivery, such as in hospitals, long-term care facilities, and ambulatory settings, and may also appear after discharge. Healthcare-associated infections also include occupational infections that may affect employees. It is also an infection acquired 48 hours after the patient's admission. Such an infection does not exist in the patient, not even in the incubation stage before his admission to a specific hospital (Alrubaiee, G et al, 2017). HAI is the most common adverse event in healthcare that affects patient safety. They contribute to increased morbidity and mortality rates and the financial burden on patients, families, and healthcare systems. Modern healthcare uses many types of devices and surgical procedures to treat patients and help them recover. The infection can be associated with devices used in medical procedures, such as catheters or ventilators. According to the US Centers for Disease Control and Prevention (CDC), these infections have the following types:

1. central line-associated bloodstream infections (CLABSI).
2. catheter-associated urinary tract infections (CAUTI).
3. ventilator-associated pneumonia (VAP).
4. surgical site infections (SSI).

(Reddy, P. L., & Chand, A. A., 2020) stated that There are several main causes of nosocomial infections that healthcare professionals must consider to effectively prevent and control their spread:

1. Patient susceptibility: Hospitalized patients are often already sick and have weakened immune systems, making them more susceptible to infection. This vulnerability increases the risk of nosocomial infections.

2. Invasive procedures: The use of invasive procedures, such as surgery, urinary catheterization, and intubation, can introduce bacteria into the body and increase the likelihood of infection.

3. Antibiotic resistance: Inappropriate or excessive use of antibiotics within healthcare settings can contribute to the emergence of antibiotic-resistant bacteria. These resistant strains pose a serious challenge in the prevention and treatment of nosocomial infections.

4. Poor hand hygiene**:** Lack of proper hand hygiene among healthcare professionals can lead to the transmission of harmful microorganisms. Regular and thorough hand washing is crucial to preventing the spread of infection.

5. Contaminated surfaces and equipment: Hospital environments, including medical surfaces and equipment, can become contaminated with harmful bacteria. Failure to adequately clean and disinfect these areas can contribute to the spread of nosocomial infections.

6. Crowded conditions: Overcrowding within healthcare facilities can facilitate the transmission of infection between patients. Proximity and shared spaces increase the risk of hospital outbreaks.

7. Lack of appropriate infection control measures**:** Inadequate implementation of infection control measures, such as isolation precautions and appropriate sterilization techniques, can contribute to the occurrence and transmission of nosocomial infections.

Infection Control Assessment Tool (ICAT)

The Infection Control Assessment Tool (ICAT) was developed under the auspices of the Pharmaceutical Governance Program in the Administrative Sciences for Health (Washington, DC) with support from USAID. The Infection Control Assessment Tool (ICAT) is designed to facilitate the identification, control, and prevention of nosocomial infections through an easily-

administered and scored instrument that highlights areas of concern and suggests economical improvements within hospitals. Many international organizations have developed standards for preventing the transmission of infections among patients and health workers. For example, the World Health Organization (WHO) has developed standards for infection control and injection safety in resource-poor hospitals, and organizations such as Engender Health and JHPIEGO have created useful approaches for implementing infection control programs in lower-level health facilities. The ICAT differs from most approaches to hospital infection control in that it offers a simple and practical approach to assessing the adequacy of existing infection control practices, and gives specific recommendations for improving them and monitoring their ongoing effectiveness. (South African National Department of Health,2013)

The ICAT in its newest version (the 2nd version, 2009) consists of 21 modules (standardized units) that provide a comprehensive assessment of infection prevention and control activities in hospital settings Each assessment module consists of groups of questions easily answered by yes/no, multiple choice, or checklist responses. The modules cover a variety of infection control topics and are easily adapted to be consistent with local government infection control standards or with the resources available in a particular setting. Each module focuses on a particular topic or a specific hospital department such as labor and delivery, intensive care, or general medical or surgical wards. Because the tool is modular, it is easily adapted for use by all types of hospitals, regardless of bed size, budget, or type (referral, regional, district, or community). It may be used in a hospital that has no formal infection control program but wishes to strengthen infection control activities; to identify weaknesses in an existing infection control program, or to target a specific infection control issue (Infection Control Assessment Tool,2009).

System architecture and design

The digital checklist system was designed to be applicable and can be used easily by healthcare professionals. The interface provides easy navigation and intuitive functionality to facilitate efficient assessment of infection control measures. The system also includes a pre-defined checklist template tailored to the unique infection control requirements of the ICU based on the ICAT with some modifications to suit the designated health care system. The template contains a comprehensive list of questions covering various aspects of infection prevention and control procedures or highly important areas in according with the ICAT's different modules, such as General ICU Practices, Mechanical Ventilation, Airway Suctioning, Hand hygiene, Intravenous Catheters, Urinary Catheters, Intravenous Fluids and Medications. Moreover, the system enables real-time data entry during the assessment process. Healthcare professionals will be able to electronically record their findings directly into the system, eliminating the need for manual data entry and reducing the chances of errors or omissions due to many restricts which will force the user to correctly answer every question with no chance to skip or misdeal with any of the questions. After finishing the assessment, the system will evaluate the compliance of infection control measures according to the same scoring mechanism used in the ICAT. Each item in the checklist will be associated with a specific scoring criterion, allowing for standardized assessment and comparison of infection control practices across different ICUs. The collected data will be stored in a structured format, allowing for easy retrieval and analysis and based on these data The system will offer reporting capabilities to generate comprehensive reports. The reports will include overall compliance scores and specific areas of improvement or concern.
Data visualization techniques, such as charts and graphs, will be employed to enhance data interpretation. The system design included four main steps:

1. checklist Development:
   The checklist was developed based on the Infection Control Assessment Tool (ICAT) specifically designed for the ICU setting (Table 1). It covers various modules. The development process involved pilot testing, validation, and iterative revisions with experts to ensure that the final checklist is evidence-based, practical, and effective in promoting infection prevention and control in the ICU.

Table 1- Checklist Modules

Section name	Section description	Maximum points
General Practices in the ICU	this module focuses on How frequently immediate patient care areas in the ICU are thoroughly cleaned, the hand hygiene and clothes rules	6
Mechanical Ventilation	this module evaluates infection control measures related to mechanical ventilation, such as proper handling and cleaning of ventilator equipment, appropriate use of respiratory hygiene measures	6
Prophylaxis and Monitoring	This section focuses on assessing infection control measures related to prophylactic interventions and ongoing monitoring protocols in the ICU. It ensures that appropriate measures are in place to prevent the occurrence and spread of healthcare-associated infections.	23
Airway Suctioning	This module assesses the infection control practices during airway suctioning procedures, including proper technique, use of sterile suctioning equipment, and adherence to aseptic procedures to prevent the transmission of respiratory pathogens.	11
Hand Hygiene	Hand hygiene is a critical aspect of infection control. This module focuses on evaluating the availability of hand hygiene equipment's and compliance with hand hygiene protocols, including handwashing techniques, use of hand sanitizers, and appropriate glove usage.	29
Intravenous Catheters	This module assesses infection control measures related to intravenous catheter insertion, maintenance, and removal. It includes evaluating proper hand hygiene before procedures, aseptic techniques during catheter insertion, adherence to sterile dressing protocols	29
Urinary Catheters	This module addresses infection control practices related to urinary catheterization. It evaluates proper insertion techniques, catheter maintenance, and timely removal to minimize the risk of catheter-associated urinary tract infections (CAUTIs).	10
Intravenous Fluids and Medications	This module focuses on infection control measures related to the handling, preparation, and administration of intravenous fluids and medications. It includes assessing aseptic techniques during medication preparation, safe disposal of sharps, and proper disinfection of medication administration equipment.	20

The table contains the sections that the checklist consists of and a description of their main focus in addition to the total score that can be gained in each one of them.

2. User Interface (UI) and Functionality:

The UI of the digital checklist system is carefully designed using Qt Designer which is a powerful tool for creating graphical user interfaces (GUIs) using widgets from the Qt GUI framework which is a very famous framework for building desktop applications, mobile apps, or embedded systems. In order to make the program intuitive and user-friendly. best practices in UI design were employed, such as clear navigation menus, intuitive icons, and visually appealing layouts, to ensure that healthcare professionals can easily navigate through the checklist and access relevant information without confusion or difficulty. The UI incorporates a logical and organized structure for navigating through different sections or modules of the checklist which were separated into different taps (figure 1). Moreover, the UI can provide real-time feedback and scoring to

healthcare professionals as they complete the checklist. display visual indicators or progress bars to show the completion status of each assessment criterion. Furthermore, to enhance usability and clarity, each question in the checklist system is accompanied by tooltip texts that provide clear and concise explanations. These tooltip texts serve as contextual help, offering additional guidance and clarification on the meaning and intent of each question. a message dialog that alerts and warns the user when attempting to leave a question unanswered is presented. This functionality is designed to promote thoroughness and completeness in the assessment process and prevent unintentional omissions. To further enhance the user experience and minimize errors, the checklist system includes a "SAVE" feature. This feature allows users to review and save their responses and make any necessary revisions or corrections before finalizing and submitting the completed checklist (figure 2).

Once the user has completed all the questions in the checklist, they can choose to review their answers by selecting the "save" button or a similar option. This action will save the answer in a separate file and open a summary page displaying all the answered questions along with their respective responses.

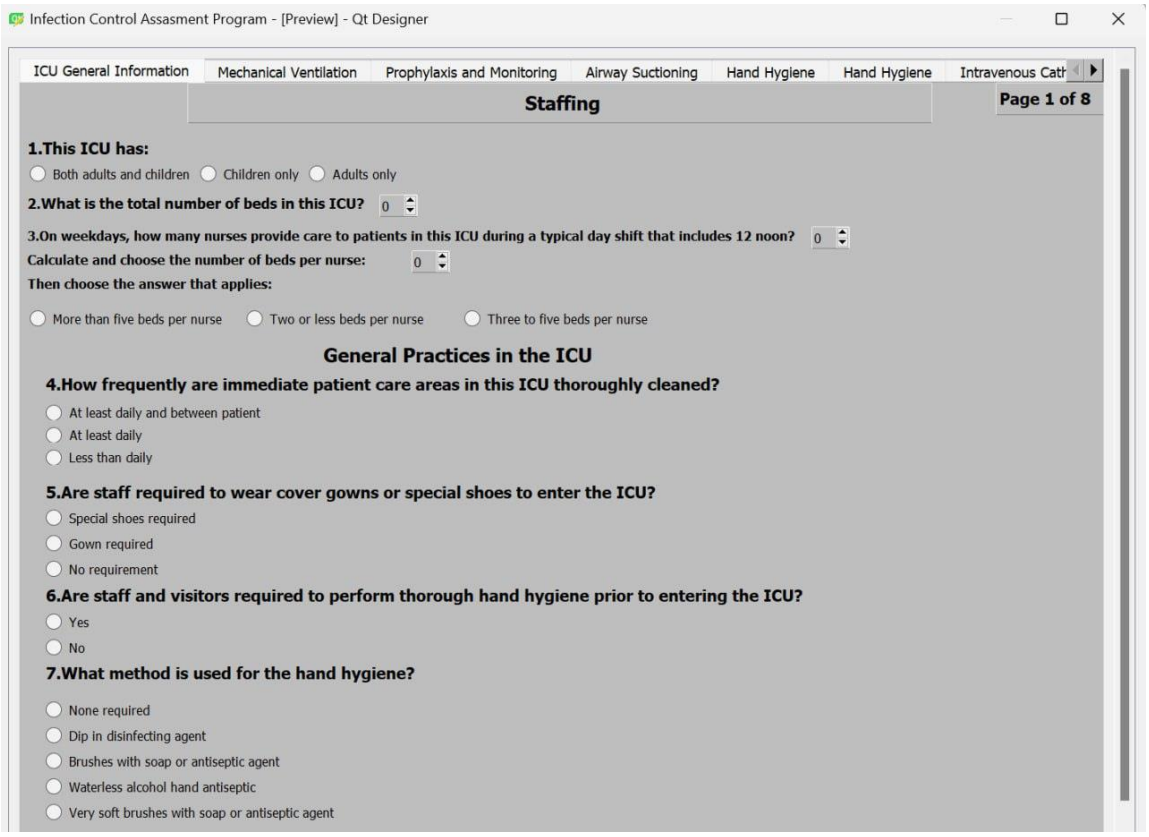

Figure 1- ***The General Practices and staffing Section***

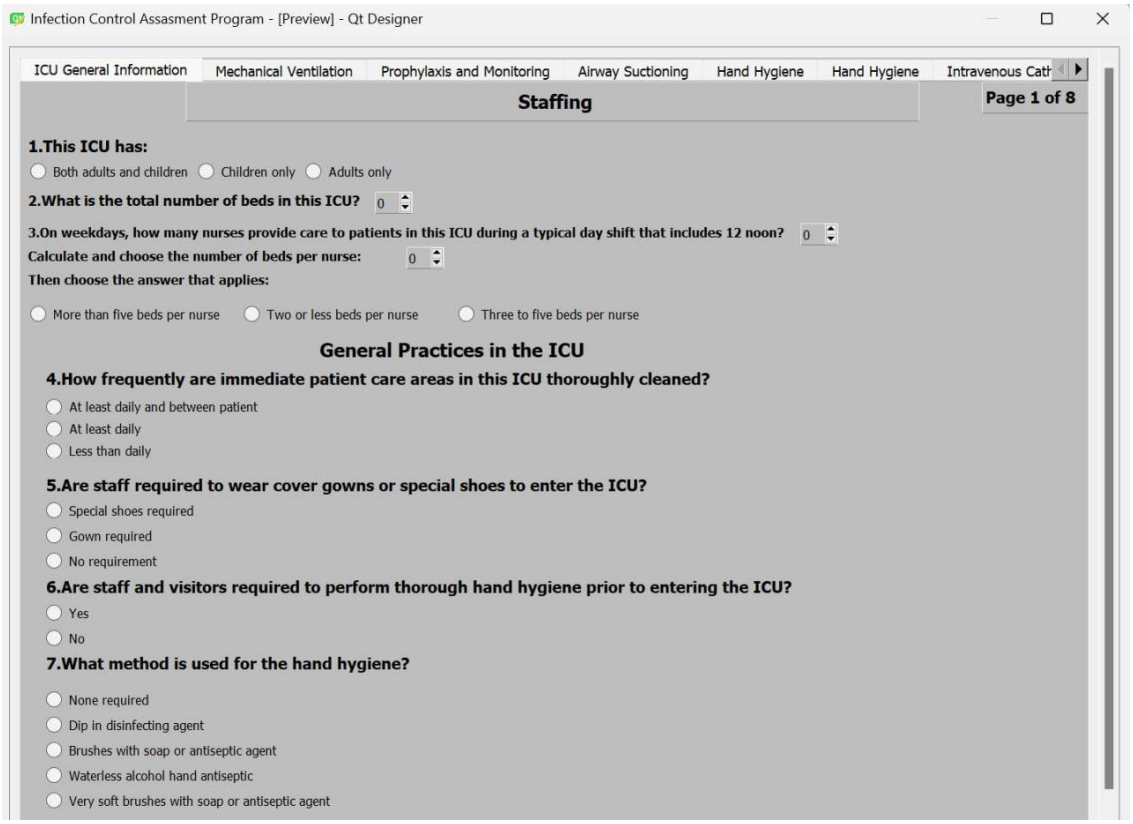

Figure 2- ***The Submitting or saving way at the end of the Assessment***

3. Reporting and Analysis

during the assessment process, the system was designed to aggregate and securely store the collected data in a centralized database which was designed using SQL Server programming language. It ensures proper data governance, including privacy and security measures, to protect sensitive information and comply with any relevant regulations and standards. Moreover, it supports data analysis by providing tools and functionalities to explore and interpret the collected data. It includes built-in analytical capabilities, such as data visualization, and statistical analysis. These features enable healthcare professionals and administrators to gain meaningful insights. Furthermore, the reports generated by the system can identify specific areas of non-compliance, high-risk practices, or opportunities for targeted interventions. This information can guide quality improvement teams in developing and implementing strategies to enhance infection control practices, reduce healthcare-associated infections, and improve patient outcomes (figure 3). The assessment report is divided into four main sections:

1. The score of each assessed section in comparison with the maximum scores of points that can be gained
2. Summary charts (bar graphs, pie charts, etc.) to visually represent the results
3. Assessment conclusion which defined the gaps and the best practices that were noticed via the assessment
4. Recommended practice to overcome the weak points in the infection control practices in different areas in the ICU.

The overall quality of the practices measured in each section is summarized using the same three broad categories mechanism used in ICAT:

- Excellent practice in this topic area (75% or more of the possible points) which means that recommended practices were followed systematically and exhaustively
- Good practice in this area (50%-74% of possible points) which shows that recommended practices were generally followed
- Poor practice that needs attention (fewer than 50% of possible points) which means that the health facility needs training and follow-up on recommended practices.

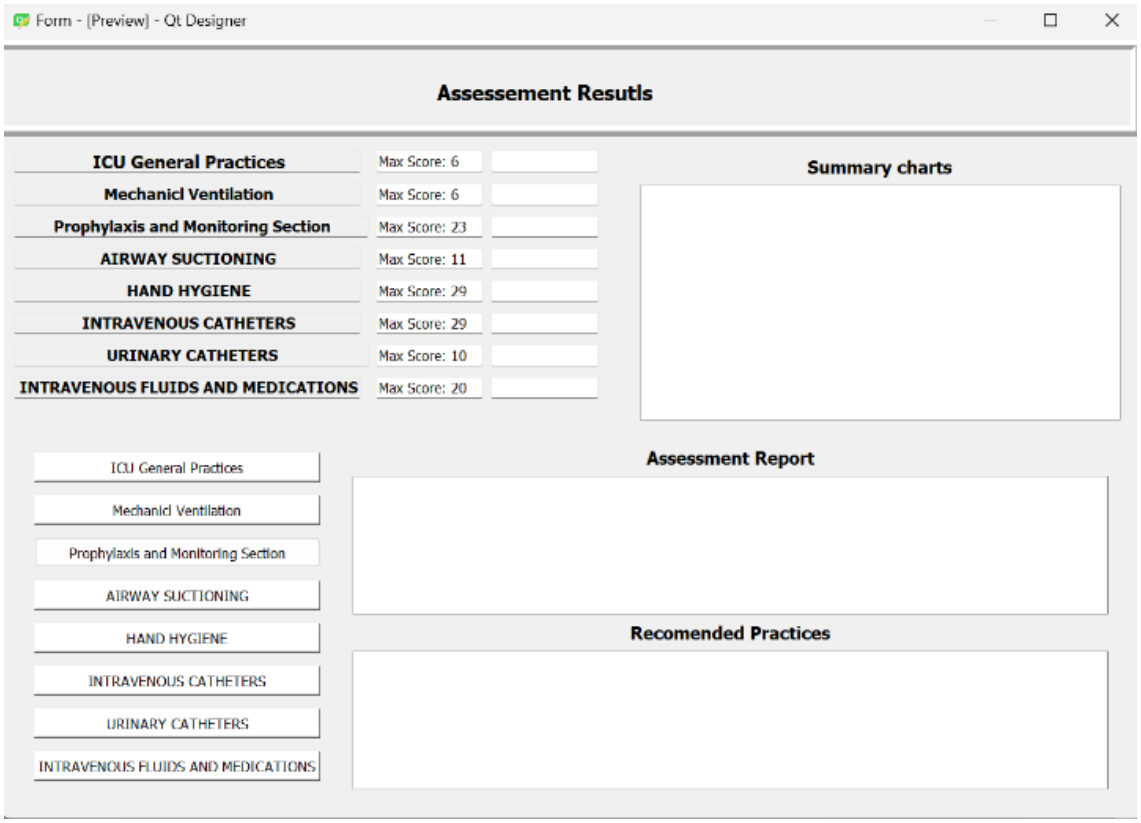

Figure 3- ***The Digital Checklist System Report Page***

4. System testing and evaluation

To evaluate the effectiveness and practicality of the checklist system, it was tested and implemented in two different Medical ICUs (MICU) in different two private hospitals in Lattakia, Syria in February 2024, namely ICU A and ICU B. The goal was to assess infection control practices, identify opportunities for improvement in each ICU setting, and make sure that the program is fully functional. During the testing phase, the checklist system was deployed in both ICUs and the head of both units actively used it to conduct assessments of infection control measures. The system's functionalities, including data collection, reporting, and analysis, were thoroughly evaluated in real-world ICU environments.

4. Results and Discussion

The overall scores obtained by both ICUs were above 75% for five of the eight modules. The scores obtained are listed and compared between both A and B ICUs (Table 2).

both ICUs gained more than 75% of the overall score in ICU general practice, both reported having sufficient nursing staff with a 1:2 nurse-to-patient ratio and gained 2 points for this. Also,

immediate patient care areas in both ICUs were thoroughly cleaned At least daily and between patients and gained an additional 2 points for this. None of the ICUs scored full marks in the general practices section as the question of Are staff and visitors are required to perform thorough hand hygiene before entering the ICU was answered with no for both ICUs.

In the section on mechanical ventilation, the overall score was 60% for ICU A, and ICU B had a lower overall score of 50%. The low scores in this section were due to variations in the ventilator circuit changing period and the type of humidifier which is used in the ventilator circuit. Both ICUs gained high points in the section on Prophylaxis and monitoring due to having written procedures for most of the tested cases, good blood glucose monitoring, and providing eligible patients with prophylaxis for the most needed conditions.

For the Airway suctioning section, the overall score for both ICUs was similar (60%). None of the ICUs complied with the recommended frequency of change of the airway suction catheter and wore sterilized gloves on both hands while suctioning. Both ICUs scored more than 75% of the overall score in the section on hand hygiene practices. In the section on HH equipment and supplies, both ICUs did not meet the ratio of Fewer than one hand washing station per two beds with also some minor shortages in some supply areas.

In the Intravenous catheters section, both ICUs gained more than 75% of the overall score while both of them lost points in the question on the type of antiseptic used for inserting IV catheters, six options scored a point each. both ICUs used chlorhexidine only and therefore did not score the full points for this question.

On the other hand, In the section on Urinary catheters, both ICUs failed to pass the percentage of 75% of the overall score. None of the ICU heads listed all the indications for an indwelling catheter; In the question on how to obtain a urine sample from a patient with an indwelling catheter, two options scored a point each: aspirate through a special aspiration port or aspirate through catheter or collection tubing. In both ICUs, only one method was used (aspirate through a special aspiration port); therefore, none scored fully on this question.

The overall score in the section on Intravenous fluids and medications in both ICUs was over 75%. Premixed IV fluids were commercially sourced and the commercial IV infusion tubing was always compatible with the bottles or bags used in the unit. both ICUs reported that the admixture of standard IV fluids (e.g. adding potassium chloride) was at the patient's bedside and not at the pharmacy as recommended in the ICAT. Also, both ICUs reported changing the infusion tubing of blood products only when the infusion was complete which is also the same for changing the infusion tubing for total parenteral nutrition fluids and dextrose/ saline fluids.

During the testing and implementation of the checklist system in ICU A and ICU B, feedback was collected from the heads of both ICUs. they provided positive feedback regarding the system's functionality and usefulness in assessing infection control practices. However, they also expressed a need for some customization to align the system more closely with their specific requirements and workflows. The customization needs were about modifying certain checklist questions, response options, and data fields to align with the specific infection control protocols and documentation practices of ICU A and ICU B. Additionally, the system's reporting and analysis features were further tailored to provide more relevant and actionable insights based on the ICUs' specific quality improvement goals.

Overall, the results of the assessments indicate a satisfactory level of adherence to recommended practices in several key areas, including sufficient nursing staff, thorough cleaning of patient care areas, prophylaxis and monitoring, and intravenous fluids and medications. These positive outcomes reflect the dedication and efforts of healthcare professionals in ensuring patient safety and reducing the risk of healthcare-associated infections. However, the study also identified areas that require attention and improvement. Challenges were observed in hand hygiene compliance, mechanical ventilation practices, airway suctioning protocols, and urinary catheter practices.

These findings highlight the need for targeted interventions and continuous quality improvement initiatives to address these gaps and enhance infection control practices in the ICUs. Furthermore, the feedback obtained from the heads of both ICUs regarding the checklist system's functionality and usefulness underscores the importance of more collaboration with healthcare professionals. This feedback-driven customization process resulted in tailored modifications to better align the system with the specific requirements and workflows of different healthcare systems, indicating the system's adaptability and potential for enhancing infection control practices in diverse ICU settings.

Table 2-Assessment Results

Section name	ICU A	ICU B	Maximum points
General Practices in the ICU	4	5	6
Mechanical Ventilation	4	3	6
Prophylaxis and Monitoring	18	20	23
Airway Suctioning	6	6	11
Hand Hygiene	25	24	29
Intravenous Catheters	22	24	29
Urinary Catheters	5	4	10
Intravenous Fluids and Medications	16	15	20

The table shows the scores of each section for both ICUs in addition to the total score that can be gained in each section.

5. Conclusion

In conclusion, this research aimed to assess infection control practices in ICU settings using a checklist system. By evaluating the implementation of infection control protocols and measures in real ICU environments, we were able to gain insights into the adherence to recommended practices and identify areas for improvement. The findings of this study shed light on the effectiveness of digital systems as tools for monitoring and enhancing infection control practices. The implementation of the digital checklist system proved to be valuable in capturing data on infection control indicators and facilitating data-driven decision-making.

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