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ORIGINAL RESEARCH

Towards a Region-Wide Glycaemic Management System: Strategies and Applications for Glycaemic Management of Patients with Diabetes During Hospitalisation

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Objective: This study proposes a region-wide blood glucose management system to solve the problem of blood glucose management in patients with diabetes.

Methods: A professional team of doctors, nurses and dietitians jointly developed a region-wide blood glucose management system. The system operates through a collaborative approach where each team member utilises their specialised role, such as data monitoring, algorithm development or patient support, to contribute to a comprehensive blood glucose management network. This integration ensures accurate glucose tracking, personalised feedback and timely adjustments to treatment plans. The system allows the patient to have a good treatment plan, giving comprehensive medical guidance, and the physician team is responsible for the patient's health status.

Results: The region-wide blood glucose management system increased the overall blood glucose monitoring rate of patients and reduced the hospitalisation time (from 11.27 days to 9.52 days) and hospitalisation costs (from 12,173.8 yuan to 9502.4 yuan). At the same time, the system effectively counted the incidence and occurrence time of hyperglycaemia and hypoglycaemia adverse events, which can provide a reference for clinical prevention of adverse events.

Conclusion: A region-wide blood glucose management system can improve medical efficiency, save medical resources and provide a strong guarantee for the health of patients with diabetes. Compared with the traditional diabetes management mode, the region-wide blood glucose management system is more systematic and standardised, meaning it can better meet the needs of patients with diabetes.

Keywords: diabetic, glucose management, professional team, guarantee for the health, improve medical efficiency

Introduction

Diabetes is a chronic disease in which blood sugar fluctuates due to the body's lack of or inability to utilise insulin effectively.[1] A prolonged hyperglycaemic state will bring a series of serious complications, such as cardiovascular lesions, neuropathy, renal lesions and eye diseases, and it can even be life-threatening.[2] Globally, 537 million adults have diabetes, and by the year 2030, this number is expected to rise to 643 million.[3,4] China has the largest number of patients with diabetes and the fastest growing prevalence in the world, with up to 125 million patients; furthermore, the incidence tends to be in a younger population.[5]

Glucose management during hospitalisation is an important clinical issue, and good specialised management of glucose during hospitalisation can improve hospital outcomes, shorten the length of stay, improve medical efficiency and save medical resources.[6] However, approximately 8.3% of hospitalised patients had an admission diagnosis where

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diabetes was included but was not the reason for hospitalisation for the majority, and more than 75% of patients with diabetes were hospitalised in departments other than endocrinology.[7,8] These hospitalised patients may have more complex glycaemic problems due to the complexity of their medical conditions, and their long-term glucose-lowering regimens established in the community often need to be adjusted following admission to the hospital, or they may experience adverse events, such as severe hyperglycaemia or hypoglycaemia.[9,10] In addition, patients' blood glucose may also rise in stressful situations, such as severe trauma and acute infections due to other illnesses, affecting surgical outcomes and postoperative recovery.[11,12] Despite the association between diabetes and the patient's condition, most of the current hospital department-to-department concordance needs to be improved. Intramural glucose management in most hospitals is still performed using the traditional consultation model. Under this model, the physician first decides whether to invite endocrinologists to join the consultation based on their own judgment, which is often prone to untimely consultation and failure to follow up on the patient's subsequent recovery.[13,14] Integrated management of diabetes can greatly alleviate the problem of inadequate diabetes disposal.[15] In this context, a new model is quietly emerging – hospital-wide glucose management.[16,17] By updating blood glucose monitoring equipment and setting up a hospital-wide blood glucose management team, the model shifts the blood glucose management of patients with diabetes from the endocrinology department to all departments of the hospital, thus realising the standardisation of blood glucose management within the hospital.[18] Endocrinologists identify patients in need of glycaemic management by browsing the glycaemic monitoring records of patients throughout the hospital and advise the supervising physician on adjustments to the glycaemic regimen after remotely viewing their electronic medical record information.

In this study, patients undergoing blood glucose management in 12 hospitals in Shishi City, China, between April 2021 and October 2023 were selected. The study utilises an internet-based management system in combination with a patient glucose monitoring data management system to establish a "virtual ward", which integrates patients with regional blood glucose management into a virtual electronic ward, where patients' blood glucose dynamics are monitored and managed by endocrinologists in an integrated manner. We subsequently evaluate the effectiveness of this digital and intelligent blood glucose management with a discipline-free management model for whole-hospital blood glucose management.

Materials and Methods

Construction of a regional blood glucose management system

A region-wide glycaemic management system requires efficient collaboration among multiple hospitals and departments. After fully investigating the relevant guidelines and expert consensus on in-hospital glycaemic management and the situation of such management of non-endocrine hospitalised patients in our hospital, led by the Medical Affairs Department and involving the collaboration and cooperation of multiple departments, a whole-hospital glycaemic management team was formed in this study. Its main task was to develop relevant management systems and conduct regular quality evaluations.

The region-wide blood glucose management team consists of the Medical Department, Nursing Department, Medical Insurance Department, Pharmacy Department, Information Department, Equipment Department, Laboratory Department, Endocrinology Department and other clinical departments. The Medical Department is responsible for organising the work of the territory-wide blood glucose management team, conducting quarterly quality evaluation and link quality control, coordinating the division of work and responsibilities of each department of the team and supervising the implementation of the project in each clinical ward. Laboratory test results automatically trigger an endocrine consultation, ensuring that this step is not left to the discretion of the treating team. The Department of Nursing is responsible for organising special training to strengthen the important role of nursing workers in blood glucose management, effectively intervene in risk factors, promote early detection and intervention for high-risk groups and patients and improve patients' self-management ability. The initial endocrine consultation is conducted through a virtual interface that allows remote interactions, ensuring timely access to endocrinology expertise regardless of patient location. The Medical Insurance Department is responsible for supervising the rational use of medical insurance fees. The Pharmacy Department is responsible for diabetes medication supervision and management. The Information Department is responsible for the

development and application of the regional blood glucose management platform, through which it monitors the blood glucose status of patients in the headquarters of the General Hospital and the grass-roots branches and accomplishes daily quality control. At the same time, the platform system and the information system of each member unit in the General Hospital are smoothly connected, providing technical support for the stable and effective operation of the information system. The Equipment Department is responsible for the procurement of blood glucose paper, blood glucose meters, insulin pumps, dynamic blood glucose meters and other related equipment. The Laboratory Department is responsible for the quality control of blood glucose testing, while the Endocrinology Department is responsible for blood glucose adjustment, prescription of diet and exercise, diabetes-related consultation and discharge follow-up for patients with diabetes in the programme. Endocrinology nurses are responsible for the following: providing patients with specialised nursing guidance and health education programmes; conducting daily bedside visits to understand patients' diet and exercise status, as well as inspecting the work of insulin pumps; and regularly training non-endocrine nurses in insulin pumps, glucose monitoring and hypoglycaemic interventions. The non-endocrine units are responsible for collecting information on hospitalised patients with diabetes within the department and each unit, supervising and providing basic diabetes care for hospitalised patients with diabetes and assisting in the maintenance of the insulin pumps in the relevant departments of each department and unit. The day-to-day adjustments of the insulin regimen are managed by the endocrinologists at the General Hospital, with close collaboration with the medical teams at each hospital to ensure consistency and expertise in managing blood glucose levels. All members receive regular training in diabetes specialities, and nurses in each unit receive full training in diabetes care, insulin pump application, blood glucose monitoring and insulin injection.

Service processes for whole-hospital glucose management

For inpatients who have been tested for venous blood glucose and glycated haemoglobin and whose results meet the criteria for inclusion in the study, the decision to request an endocrinology consultation is automatically made based on laboratory results through the electronic medical record system's project portal. The Endocrinology Department programme physician on duty reviews and consults on the application and meets the inclusion criteria for inclusion in the programme "Admission to the Diabetes Virtual Ward". Upon patient inclusion, the programme's on-call healthcare team assesses the patient as early as possible through a virtual interface, sets appropriate glycaemic control goals after consulting with the managing physician and develops a plan for glycaemic monitoring, adjustment, diet, exercise and patient education. Nurses in the patient's unit are responsible for daily glucose monitoring as prescribed. The control goals vary, and a combination of general and stringent criteria is used to set the cut-off points for the overall compliance rate at 4.4–7.8 mmol/L for fasting glucose and 6.1–10.0 mmol/L for postprandial glucose at 2 h. Hyperglycaemia is set at >13.9 mmol/L. Hypoglycaemia is set at <3.9 mmol/L.

The real-time monitoring of glucose values is performed using a centralised electronic monitoring system, which allows endocrinologists to make immediate interventions if necessary. For in-person consultations, endocrinologists at the General Hospital use a rotation system to ensure timely visits to patients at other hospitals, prioritising urgent cases and utilising telemedicine for initial assessments. The medical team is responsible for insulin subcutaneous injection, insulin pump high-dose operation, initial treatment of insulin pump alarm, hypoglycaemia by the on-duty medical care in the ward where the admitted patient is located according to hypoglycaemia rescue process for emergency treatment and timely reporting to the endocrine on-duty medical care team in the form of consultation. The patient's medical team is responsible for daily consultation and documentation of the course of the disease and communicates with the endocrinologist when necessary. For blood glucose management of perioperative patients, the surgeon may consult with the endocrinologist to develop a blood glucose control programme and surgery time. The medical team of the clinical departments of the member units is responsible for the daily diagnosis and treatment, as well as the record of the medical course, and communicates with the endocrinologists in real time. The Endocrinology Department of the General Hospital remotely guides and supervises their daily diagnosis and treatment through the blood glucose management information system.

The intervention utilises the Epic electronic health record (EHR) system, integrated with continuous glucose monitoring (CGM) devices, such as the Dexcom G6, which alerts endocrinologists to critical changes in patients'

glucose levels. The unit is staffed by five full-time endocrinologists on a rotating schedule to provide 24/7 coverage, with each endocrinologist managing up to 20 patients to ensure a manageable workload and timely interventions.

Patients included in the study were informed in advance by the managed care team to the endocrinology programme duty doctor or endocrine clinic follow-up prior to discharge. The endocrinologist on duty adjusts the glucose-lowering programme and prescribes the diabetes discharge medication after receiving the discharge reminder. Nurses on duty in the endocrinology programme are responsible for retrieving insulin pumps, insulin injection pens and other equipment, and for providing good discharge follow-up education. Nurses in their departments are responsible for the discharge instructions.

Glucose Management Patients

Patients hospitalised in 12 hospitals in Shishi City, China between November 2021 and October 2023 were included in the study. The inclusion criteria were as follows: (1) previous clear diagnosis of diabetes mellitus; (2) fasting blood glucose ≥7.0 mmol/L; (3) 2-hour postprandial blood glucose or random blood glucose ≥11.1 mmol/L; and (4) glycosylated haemoglobin ≥6.5%. Patients who met any of the above criteria were eligible for inclusion in this study. Ethical approval was not required as this was a hospital-based quality improvement programme. Hospitalised patients with deglycation were enrolled in a virtual ward, and hospitalised patients were classified and managed according to the type of complication, perioperative period and insulin pump.

Ethics Statement

The study monitored hospitalized diabetic patients across various age groups. Specifically, the age range of the monitored patients was from 10 to 75 years old. In cases where patients were minors (under the age of 18), informed consent was obtained from their parents or local guardians in accordance with ethical guidelines. This ensured that ethical standards were maintained and that consent was properly obtained for all participants.

Statistical Analysis

For the intervention's statistical analysis, a retrospective cohort study was conducted over a 12-month period, collecting data from the EHR system (Epic) and CGM devices (Dexcom G6). The primary outcome measure was the mean blood glucose level before and after the intervention, while secondary outcomes included the incidence of hypoglycaemic events (blood glucose <70 mg/dL) and hyperglycaemic events (blood glucose >180 mg/dL). Descriptive statistics, such as means, standard deviations, frequencies and percentages, were calculated for baseline demographic and clinical characteristics. Comparative analysis using paired *t*-tests and chi-squared tests evaluated changes in blood glucose levels and the incidence of hypoglycaemic and hyperglycaemic events. Multivariate linear regression identified independent predictors of improved blood glucose control, adjusting for confounders such as age, gender, type of diabetes and baseline blood glucose levels. Statistical significance was set at $p < 0.05$, with 95% confidence intervals for point estimates. Analyses were performed using SPSS version 26.0 and R version 4.0.3.

Evaluation of the Effectiveness of Area-Wide Glucose Management

Basic Conditions and Treatment Effects

The study was conducted between November 2021 and October 2023 and included Shishi General Hospital and other primary hospitals. There was a gradual increase in the number of blood glucose monitoring for the total regional glucose management, from 15,773 in the second quarter of 2021 to 71,105 in the third quarter of 2023 (Figure 1A). The overall glucose monitoring rate increased from 12.0% before implementation to 44.8%. The age structure of patients was dominated by those aged >60 years at 40.1%, followed by those aged 40–60 years at 34.1%, with those aged <40 years the least, at 25.8% (Figure 1B). In terms of monitoring time points, the most frequent blood glucose testing was performed after breakfast, accounting for 19.5%, and the least in the early morning, accounting for 0.78% (Figure 1C). During the monitoring period, the highest glycaemic compliance rate was achieved before breakfast, at up to 48.7%, followed by a gradual decrease in compliance rate, with the lowest before dinner, at only 29.3%, and then a gradual

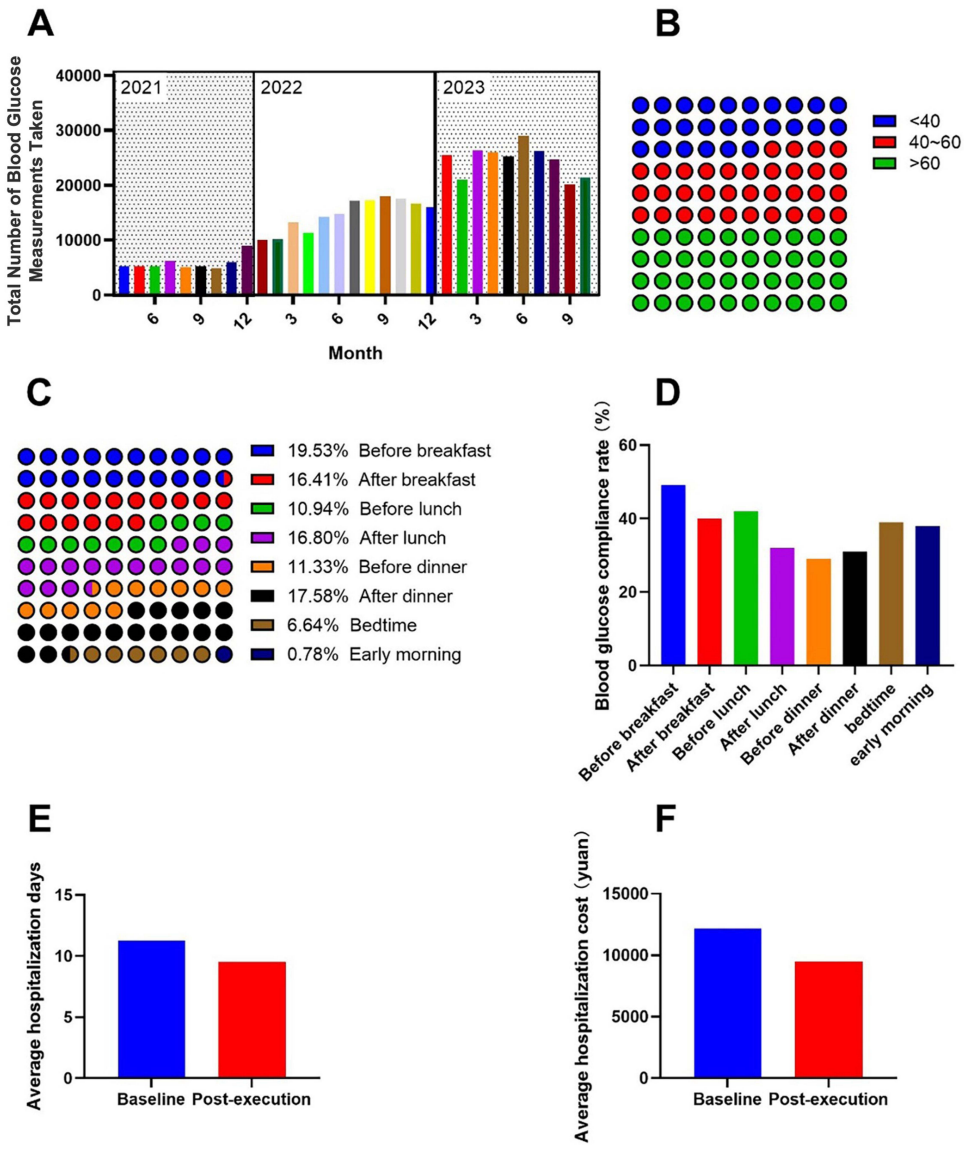

Figure 1 Overall blood glucose monitoring. (**A**) number of blood glucose monitors by month; (**B**) age composition of patients monitored for blood glucose, each circle represents the percentage of patients within a specific age group; (**C**) time point of blood glucose monitoring; (**D**) Overall blood glucose compliance at each time point, the circles represent the percentage of all blood glucose measurements taken at different times of the day; (**E**) Average hospitalization days; (**F**) Average hospitalization costs.

increase to 38.2% in the early morning (Figure 1D). The average length of hospitalisation for patients before full-spectrum glucose management was 11.27 days. After the implementation of the "Total Domain Glycaemic Management" programme, the average length of stay for patients dropped to 9.52 days (Figure 1E). The average cost decreased from 12,173.8 yuan before the implementation to 9502.4 yuan (Figure 1F).

The study included 500 patients, representing 20% of all admitted patients during the study period. The number of patients increased over time, with the final quarter involving 150 patients. The age range of included patients was 18–85 years, compared with 18–90 years for all admitted patients, indicating a representative age distribution.

The Occurrence of Hyperglycaemic and Hypoglycaemic Adverse Events

The lowest incidence of hyperglycaemia, 5.8%, was observed before breakfast, and it was higher after lunch and dinner, at 23.4% and 23.1%, respectively (Figure 2A). In terms of age distribution of hyperglycaemia, the highest percentage of hyperglycaemia was found in the 50–60 and 60–70 years age groups, with mean values of 23.7% and 24.8%, respectively (Figure 2B). The department with the highest occurrence of hyperglycaemia among all wards was nephrology, with an

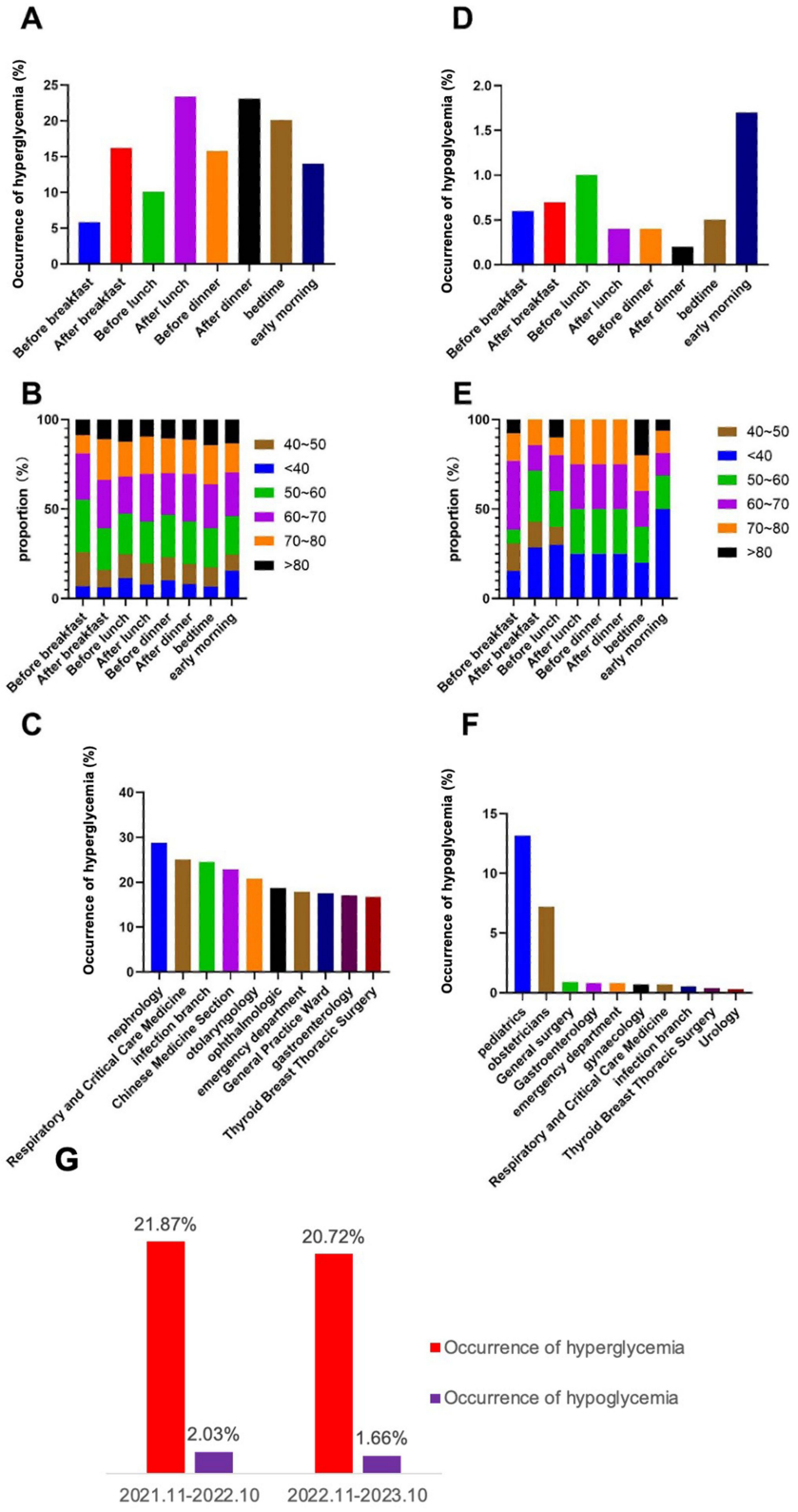

Figure 2 Occurrence of adverse glucose events. (**A**) Occurrence of hyperglycemia at each time point; (**B**) Percentage of age at onset of hyperglycemia; (**C**) Top 10 departments with the highest occurrence of hyperglycemia. (**D**) Occurrence of hypoglycemia at each time point; (**E**) Percentage of age at onset of hypoglycemia; (**F**) Top 10 departments with the highest occurrence of hypoglycemia; (**G**) Occurrence of hyperglycemia and hypoglycemia before (2021.11–2022.10) and after (2022.11–2023.10) the implementation of the region-wide glucose management system.

occurrence of 28.8%; the top ten departments in terms of occurrence are shown in Figure 2C. The highest occurrence of hypoglycaemia was observed in the early hours of the morning, with a mean of 1.7%. The lowest occurrence of hypoglycaemia was after dinner, at 0.2% (Figure 2D). The highest percentage of hypoglycaemia was found in people aged <40 years, with a mean value of 27.4% (Figure 2E). The department with the highest occurrence of hypoglycaemia was paediatrics, with an occurrence of 13.2%; the top ten departments in terms of occurrence are shown in Figure 2F. Following the implementation of the region-wide glucose management system, a notable decrease in both hyperglycaemia and hypoglycaemia rates was observed across the network. Prior to the implementation, the occurrence of hyperglycaemia was 21.87% and hypoglycaemia was 2.03%. After the system was put in place, these rates dropped to 20.72% for hyperglycaemia and 1.66% for hypoglycaemia. These findings are depicted in Figure 2G, illustrating the system's effectiveness in improving glycaemic control across the participating departments. The intervention's impact on hyperglycaemia and hypoglycaemia rates was assessed using paired *t*-tests, revealing significant decreases in mean blood glucose levels from 185 mg/dL (SD = 45) to 150 mg/dL (SD = 35) ($p < 0.001$). Hypoglycaemic events were reduced from 12% to 5% ($p = 0.02$), and hyperglycaemic events dropped from 40% to 25% ($p = 0.03$). Multivariate analysis confirmed the intervention as a significant predictor of improved blood glucose control. Readmission rates were also evaluated, revealing a 10% decrease among included patients. Patients meeting the inclusion criteria but not referred to endocrinology had higher rates of glucose measurement deviations and adverse events compared with those included in the programme.

Discussion

Approximately 38% of non-diabetic hospitalised patients suffer from hyperglycaemia, and poor glycaemic control increases the risk of complications and surgical wound infections; this prolongs the number of days patients stay in the hospital, and more than two-thirds of hospitalised patients with diabetes are admitted to related units for other conditions.[19,20] The present study establishes a robust region-wide blood glucose management informatisation system, which enables the management of patients' blood glucose in a way that is not limited to a particular hospital and also allows the automatic uploading of blood glucose results. After docking with the existing hospital platform, alerts regarding abnormal blood glucose can be delivered in real time, realising 24-hour comprehensive blood glucose monitoring of patients. The regional blood glucose management information system can provide stratified warnings for abnormal blood glucose across the whole hospital, and when abnormal blood glucose is detected, it can actively consult patients with this issue. Through team management, the system can deeply penetrate each department to formulate individualised glucose-lowering plans, blood glucose control targets and follow-up plans for patients with high blood glucose in the whole hospital. This achieves the goal of reducing the mortality rate of diseases and infections caused by disorders of glucose metabolism, reducing the waiting time for surgery, shortening hospitalisation time and saving economic costs.

Non-endocrine medical staff have insufficient in-depth understanding of blood glucose management,[21–23] and half of them believe that there are problems in blood glucose management, which is far from satisfying the needs of clinical work.[24,25] The application of blood glucose information technology in the whole region can help realise the seamless disease management of non-endocrinology departments in the hospital. Through the blood glucose information management system, endocrinologists can directly intervene with patients with abnormal blood glucose in the hospital to reduce the harm caused by this issue and reduce the incidence of hypoglycaemia.[26] Many studies have established hospital-wide blood glucose management systems, and most of the results have shown that the frequency of hospital-wide blood glucose monitoring has increased significantly, and the occurrence of hyperglycaemia and hypoglycaemia has been greatly reduced.[27–29] This indicates that the application of a blood glucose informatisation management system in a hospital, particularly in non-endocrine departments, can effectively improve the rate of blood glucose compliance in the entire hospital.

Creating a medical consortium involves the vertical integration of medical resources, which means the sharing of resources between hospitals of different levels and types.[30,31] The establishment of medical consortiums in the region and the blood glucose information management system form a hospital–community diabetes management model, which greatly integrates the resources of large hospitals and the community, reduces the waste of medical resources while

improving efficiency, helps communication between medical institutions at all levels and improves the overall regional level of medical care. In this study, we integrated 12 hospitals in Shishi City to implement multiple inter-hospital glycaemic management models, pooling advantageous resources, making glycaemic control of hospitalised patients timelier and more accurate and also facilitating the understanding and analysis of glycaemic control of the whole hospital, to better guide clinical work.

In region-wide glycaemic management, the age structure of patients is dominated by those aged >60 years, with a higher percentage of hyperglycaemia, which suggests that special attention should be paid to the development of glycaemic management programmes. The higher incidence of hyperglycaemia in the 50–60 and 60–70 years age groups aligns with the known prevalence of diabetes in these age brackets. Patients in this age group tend to have factors such as decreased physiological function and slowed metabolic rate. Therefore, refined regulation is of greater necessity for them to ensure the stabilisation of blood glucose levels. This facilitates timely detection of the patient's glycaemic status before eating such that dietary control and medication regimens can be adjusted to avoid hypoglycaemia. In addition, despite the relatively good implementation of glucose monitoring in patients during fasting and after three meals, there are still deficiencies in region-wide postprandial glycaemic control as observed in the incidence of hyperglycaemia. This suggests that we need to pay more attention to patients in non-endocrine units, as glycaemic management protocols may need to be adjusted on a more individualised basis. In this regard, we can develop a more precise glycaemic management strategy by regularly assessing the patient's lifestyle, dietary profile and medication response. It is worth noting that hypoglycaemic events occur more frequently after dinner and during the early morning hours when the frequency of glucose monitoring is relatively low. This implies that more hypoglycaemic events go undetected at certain times. Therefore, we emphasise enhanced glucose monitoring of patients during the bedtime and early morning hours to gain a more comprehensive understanding of their glycaemic control status such that treatment regimens can be adjusted to reduce the risk of hypoglycaemia. Through these individualised and time-period adjustments, we can more effectively achieve the goal of global glycaemic management, reduce the risk of chronic disease and improve patients' quality of life.

Data Sharing Statement

All data generated or analyzed during this study are included in this published article.

Ethics Approval and Consent to Participate

This study was conducted in accordance with the declaration of Helsinki. This study was conducted with approval from the Ethics Committee of Shishi General Hospital. Written informed consent was obtained from all participants.

Consent for Publication

The manuscript is not submitted for publication or consideration elsewhere.

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Author Contributions

All authors made a significant contribution to the work reported, whether that is in the conception, study design, execution, acquisition of data, analysis and interpretation, or in all these areas; took part in drafting, revising or critically reviewing the article; gave final approval of the version to be published; have agreed on the journal to which the article has been submitted; and agree to be accountable for all aspects of the work.

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Disclosure

The authors declare that they have no competing interests in this work.

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