Perioperative Glycemic Management in Insulin Pump Patients Undergoing Noncardiac Surgery

Basem Abdelmalak1,*, Michael Ibrahim2, Jean-Pierre Yared3, Mary Beth Modic4 and Christian Nasr5

1Associate Professor of Anesthesiology, Associate Director, Preoperative Anesthesia Consultation and Evaluation Clinic, Departments of General Anesthesiology and Outcomes Research, Director, Center for Sedation, Anesthesiology Institute, Cleveland Clinic; 2Internal Medicine Resident at The Wright Center-Regional Hospital of Scranton, Scranton, PA; 3Director, Center for Critical Care Medicine, Heart and Vascular Institute; Depts. of Cardiothoracic, Anesthesiology and Outcomes Research, Anesthesiology Institute, Cleveland Clinic; 4Clinical Nurse Specialist- Diabetes, Nursing Institute, Cleveland Clinic; 5Co-director, Thyroid Center; and Department Quality Improvement Officer, Dept. of Endocrinology, Endocrinology and Metabolism Institute, Cleveland Clinic, OH 44195, USA

Abstract: Increasingly more Americans are being diagnosed with diabetes mellitus, and the number of those using the continuous subcutaneous insulin infusion pump (CSII), commonly known as the insulin pump, is on the rise. Although evidence is lacking on how best to manage insulin pump patients perioperatively, several individual or institutional approaches have been developed. Here we propose a comprehensive algorithm for perioperative glycemic management in insulin pump patients undergoing noncardiac surgery. Where applicable, we discuss the rationale behind the algorithm.

Keywords: Perioperative, glucose control, insulin pumps, diabetes, anesthesia.

INTRODUCTION

In the United States, 2 million new cases of diabetes mellitus are diagnosed each year. About 8% of the population (26 million patients) has diabetes, and another 70 million have pre-diabetes [1]. The number of patients using the continuous subcutaneous insulin infusion pump (CSII), commonly known as the insulin pump, is also rising. Thus, anesthesiologists are expected to care for more diabetic patients and more insulin pump users than ever before [2,3].

The accepted indications for choosing an insulin pump over the more commonly used multiple daily injections (MDI) of insulin include inadequate glycemic control (despite MDI), wide glycemic variability, unpredictable severe hypoglycemia, extreme insulin sensitivity, pregnancy, unpredictable work or activity schedule, and Dawn phenomenon (hyperglycemia occurring in the early morning hours thought to happen because of increases in growth hormone and cortisol at that time) [4]. However, despite the lack of strong data proving the superiority of the insulin pump over MDI in type 1 diabetes mellitus (T1DM), patients prefer the insulin pump because of convenience, ease of use and flexibility [5]. Moreover, the use of insulin pumps is not limited to patients with T1DM. In fact, almost 10% of insulin pump users have type 2 diabetes mellitus (T2DM) [6]. It is estimated that there are more than 400,000 insulin pump users worldwide and their number is growing by 12—14% every year [7]. The majority of diabetic patients who use the insulin pump live in the United States [8,9].

The insulin pump is a small battery-operated external device which contains a refillable insulin reservoir. It delivers insulin through a small needle (also known as cannula) inserted subcutaneously. Although pumps can be worn in a variety of locations, the abdomen is the most prevalent site among patients.

In order to safely manage patients using insulin pumps during hospitalization and particularly during the perioperative period, caregivers should learn how to manage them (or help the patient manage them), as well as recognize situations in which it is advisable to transition to a different insulin administration regimen. A high rate of compliance with implementation of a policy on inpatient use of the insulin pump and with the required procedures has been reported [10].

Only limited data are available regarding the management of patients using insulin pumps in the perioperative period or for hospitalized patients in general. In the absence of such evidence, several individual or institutional approaches have been developed, most of which are specific to a particular practitioner or institution [11,12]. However, there is an important difference between nonsurgical and surgical hospitalized patients: The difference lies in the potential for iatrogenic alterations of the level of consciousness inherent in the perioperative period. Such levels range from unconsciousness during general anesthesia to somnolence following the administration of sedatives and opiates. As a result, the patient may no longer be able to complete all the necessary processes required for self-management of the insulin pump, and may in addition have difficulty accounting for variations in the intake of carbohydrates contained in IV fluids. Moreover, the patient may no longer be able to report symptoms of hypoglycemia, nor will the caregiving medical team be able to rely on observation of the consciousness level to detect hypoglycemic events.

Within the surgical population, the type of surgery itself may play a role in determining the best approach: Major surgery that triggers a large inflammatory response often results in difficulty controlling blood glucose, particularly when therapy includes administration of beta agonists or glucocorticoids, or changes in the dosage of drugs that increase resistance to insulin. Minor surgery, on the other hand, results in little or no change in metabolism, and therefore, aside from the decreased caloric intake inherent in the NPO status, it has minimal impact on insulin needs.

Our goal in building this algorithm was to increase the safety of perioperative glycemic management of patients wearing an insulin pump. Because of the limited available evidence in the literature as well as the lack of a standardized approach at our own institution, we formulated a comprehensive perioperative plan for the management of patients with an insulin pump (Fig. 1). In doing so, our aim was to better prepare caregivers to manage these patients safely from their first preoperative encounter until hospital discharge and to allow us to measure the effectiveness of the protocol and improve it if necessary.
Table 1. Summary of Available Insulin Pumps and their Characteristics and Special Features Insulin Pumps

<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>Model</th>
<th>Reservoir</th>
<th>Basal Increment</th>
<th>Bolus Programming Methods</th>
<th>Battery Life</th>
<th>Battery Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Animas (U.S.)</td>
<td>OneTouch® Ping™ Glucose Management System</td>
<td>200 plastic</td>
<td>0.025 unit</td>
<td>Menu, audio, vibrate, ezBolus</td>
<td>4-6 weeks with lithium</td>
<td>1 AA lithium or 1 AA alkaline</td>
</tr>
<tr>
<td>Roche Insulin Delivery Systems, Inc.</td>
<td>ACCU-CHEK® Spirit Insulin Pump System</td>
<td>315 –unit Disposable plastic cartridge, system with integrated filling aid</td>
<td>0.1 unit</td>
<td>Menu, tactile Bolus (audible or vibrating)</td>
<td>appx. 4 weeks (alkaline), 1 week (rechargeable)</td>
<td>One 1.5v AA alkaline or NiMH AA rechargeable</td>
</tr>
<tr>
<td>Insulet Corporation</td>
<td>OmniPod Insulin Management System</td>
<td>200-unit Reservoir integrated into Pod</td>
<td>0.05 unit</td>
<td>Menu</td>
<td>PDM: 3 weeks</td>
<td>Two AAA alkaline</td>
</tr>
<tr>
<td>Medtronic</td>
<td>MiniMed Paradigm® 522</td>
<td>Disposable shock-resistant plastic</td>
<td>0.05 unit</td>
<td>Menu, remote and Easy (audio) express</td>
<td>2 to 4 weeks</td>
<td>One AAA alkaline; readily available</td>
</tr>
<tr>
<td></td>
<td>MiniMed Paradigm® 722</td>
<td>Disposable shock-resistant plastic</td>
<td>0.05 unit</td>
<td>Menu, audio + vibration, via Menu, or direct bolus</td>
<td>2 to 3 weeks</td>
<td>One. Duracell, CR2</td>
</tr>
<tr>
<td>Nipro Diabetes Systems (U.S.)</td>
<td>Amigo</td>
<td>300 unit disposable plastic</td>
<td>0.05 unit</td>
<td>Audio, vibration or audio + vibration, via Menu, or direct bolus</td>
<td>2 to 3 weeks</td>
<td>One. Duracell, CR2</td>
</tr>
</tbody>
</table>

**CURRENTLY AVAILABLE PUMPS**

There are 5 commonly used insulin pumps, each with different accessories and supplies. Table 1 summarizes the characteristics of the various insulin pumps. (Fig. 2) illustrates an insulin pump connected and disconnected. (Fig. 3) illustrates the process of disconnecting an insulin pump. In the pump depicted, disconnecting the tubing from the inserted cannula requires squeezing and twisting from locked to unlocked marks then disconnecting the tubing from the cannula connection hub. (Fig. 4) illustrates one type (90-degree angle) of cannulas used to deliver insulin with adhesive tape and connection hub that connects to the insulin pump tubing. Insulin pump tubing comes in two sizes, 24 and 42 inches long, to accommodate different insertion sites and to allow some flexibility in wearing these pumps (pocket, waist belt, etc.) Because of the variety of pumps, their accessories and supplies, hospital pharmacies will not have pump supplies in stock. Patients should be instructed to bring pump supplies with them to the hospital if they wish to continue self-management during their hospitalization. [13].

**INSULIN DOSING VIA SUBCUTANEOUS INSULIN PUMPS**

There are two general principles for insulin dosing. The first consists of delivering insulin at a rate that covers the patient’s basal needs and such a rate could vary throughout the day to account for diurnal variations. The second is the administration of supplemental...
doses of insulin to fine tune the basal control as well as to cover additional needs in association with meals, snacks, and/or physiological stress. Insulin analogs used in insulin pumps are generally rapid acting analogs of short duration (onset of action: 5-15 min; peak: 60 min; duration: 4-5 hours) and include: Lispro (Humalog®), Aspart (Novolog®) and, Glulisine (Apidra®).

In our proposed management plan, our intention was to make the most of the patient’s own insulin pump in the perioperative period, for the sake of simplicity and safety. For example, the presence of the insulin pump platform “insulin on board function” in certain pumps, which takes into account the last insulin bolus, would prevent over-bolusing until the last bolus’s pharmacologic profile would safely allow re-dosing. Also, our proposed algorithm empowers insulin pump users to partner with clinicians as an integral part of the care plan, to enhance the patient’s safety and satisfaction. We describe below our approach to the management of insulin therapy in adult patients wearing insulin pumps and undergoing non-cardiac surgery, and/or diagnostic and therapeutic procedures.

**PREOPERATIVE EVALUATION CLINIC**

The following information should be solicited from the patient: type of insulin infusing (in particular, determination of whether the patient is using U-500 insulin in the pump); basal rate(s); insulin to carbohydrate ratio; and insulin sensitivity factor. Insulin to carbohydrate ratio is the amount of insulin needed to match the amount

---

Fig. (1). Perioperative Glycemic Management in Insulin Pump Patients Undergoing Noncardiac Surgery. Reprinted with permission, Cleveland Clinic Center for Medical Art & Photography © 2011-2012. All rights reserved.
of carbohydrate in a meal or snack in order to keep the blood glucose at an acceptable level after eating. Some of the variables that may affect this ratio include the preprandial blood glucose (BG) level, recent insulin boluses, insulin sensitivity and time of day [14]. The insulin sensitivity factor is an estimate of the magnitude of reduction in BG level induced by the administration of 1 unit of insulin. The accuracy and completeness of the patients response provide insight into how knowledgeable they are in their ability to self-manage the pump.

This information is necessary to help guide management throughout hospitalization. Most patients are very knowledgeable about how best to use their pump and titrate insulin under various circumstances. When discussing the patient’s concerns, the clinician should take into account the patient’s own experience, and also consider when changes in insulin dosage are needed while the patient is in the hospital. For patients who are to be admitted to the hospital, endocrinology consultation should be requested and carried out preoperatively if feasible, otherwise on the day of admission. Such consultation facilitates planning care and monitoring of
patient’s insulin requirements. Consultation also educates non-endocrinologists about the complexities of different pumps in relation to different physiologic circumstances. During consultation, pump settings should be confirmed, and the correct date and time settings verified. Consultation should also include discussion of the patient’s expectations regarding self-management, the patient’s responsibility, and the circumstances under which the pump should be removed. The patient’s questions and concerns about diabetes management, raised during such consult, can be disseminated to other members of the health care team.

Despite the rarity of hypoglycemia when patients are maintained on their usual basal rates while NPO (nothing per os) a 10-20% reduction of those rates is advisable in order to avoid the possibility of incidental hypoglycemia. Maintaining an appropriate basal rate would help to keep blood glucose concentrations stable overnight and when NPO [13].

DAY OF SURGERY, PREOPERATIVE AREA

The presence of an insulin pump should be documented in the nursing admission assessment and should comprise an integral part of the sign-out process whenever there is a change of caregivers or of shift, or a transition to another unit or level of care during the entire hospitalization. Institutions using an electronic medical record should place this information in an accessible central location, so that all caregivers may be informed that the patient is wearing an insulin pump. Some patients do not volunteer this information, for they assume that the care team is aware of it.

Hospital policy for managing insulin pumps should be reviewed with the patient, and the patient should give written consent to abide by the policy. The insulin pump insertion site should be examined for signs of inflammation or leakage. Date and time of cannula insertion should be documented. (Most patients will remove and replace the cannula every 3 days). Blood glucose concentration should always be checked upon the patient’s arrival at the preoperative area. If the insulin pump to be disconnected, it should be placed in a secured place outside the procedure room or given to a family member. Disposition of the pump should be documented in the medical record so that it can be easily located once the patient is alert and able to resume self-management of the pump. Glycemic management of diabetic patients using an insulin pump will depend on how long the scheduled procedure lasts, the expected duration of postoperative recovery, and whether there is expected to be X-ray, MRI, and/or electric shock for defibrillation as summarized below. In all patients, hypoglycemia (BG< 70 mg/dL and/or symptoms and signs of hypoglycemia at ≥ 70 mg/dL) should be treated immediately by stopping insulin pump infusion and administering 12.5-25 mL of Dextrose 50% IV, and BG should be re-checked after 5 minutes.

SHORT PROCEDURES (< 1 HOUR)

For procedures lasting less than 1 hour, and there is no expected exposure to ferromagnetic radiation, if the patient is normoglycemic (within patient’s own target), the pump can be left attached, secured, and running. Alternatively it can be disconnected with no additional insulin being administered. This latter option is recommended if there is a risk of exposure to a ferromagnetic field. If preoperative glucose concentration shows hyperglycemia (above the patient’s own target range), the patient should be asked to self-treat, using the insulin pump according to the routine management schedule, before the pump is disconnected and before any sedative medication is given to the patient. For very high preoperative glucose concentrations (> 300 mg/dL), intravenous insulin infusion should be considered. Such high glucose concentrations while the insulin pump is on and presumably infusing insulin subcutaneously generally indicate malfunction in the pump, disconnection or blockage of the infusion tube, problems with the cannula or with the insertion site. Under these circumstances, an alternative means of insulin delivery (such as IV insulin infusion) should be sought.

INTERMEDIATE PROCEDURES (1-3 HOURS):

For procedures of intermediate duration (total procedure and recovery time < 3 hours) with no expected major bleeding, fluid or temperature swings, the pump should be disconnected. If preoperative glucose concentration is normoglycemic (within patient’s own target range), the patient should be asked to self-treat with a bolus dose equivalent to the basal rate of 1 hour, before the pump is disconnected (hold bolus for blood glucose ≤ 110 mg/dL). If preoperative glucose concentration reveals hyperglycemia (above patient’s own target range), the patient should be asked to self-treat using the insulin pump according to the routine management schedule before the pump is disconnected and before any sedative medication is given to the patient. The use of the insulin pump to treat hyperglycemia will ensure that the patient receives the dose that they are accustomed to, based on knowledge of their own insulin sensitivity factor. Since most insulin pumps utilize fast-acting insulin analogs, the patient will receive timely and effective glycemic control. Insulin pump users generally know how to manage their insulin needs, and are well versed in how to use the pump. The “one hour dose” (insulin bolus dose equal to the amount of insulin infused in one hour) is chosen regardless of whether the procedure lasts one, two or three hours; because it is simple and err on the side of the hyperglycemia rather than hypoglycemia. This precaution is taken in light of NPO status and a certain degree of hyperglycemic surgical stress response. Avoidance of hypoglycemia as well as continuing controversy regarding the target range for glucose in the hospital setting both motivated the authors’ recommendation to err toward hyperglycemia rather than hypoglycemia, since the latter is more detrimental [2].

For very high preoperative glucose concentrations (> 300 mg/dL), as well as for intermediate procedures with expected major bleeding, fluid or temperature swings, intravenous insulin infusion should be considered, as recommended below, for long procedures.

LONG PROCEDURES (>3 HOURS)

For longer procedures (> 3 hours including recovery time), we recommend disconnecting the insulin pump and utilizing continuous insulin infusion. Although the pump must be disconnected, the can remain in place (Figs. 2 and 3). If the preoperative blood glucose concentration is within target (<180 mg/dL), an intravenous insulin infusion should be started at 2/3 of the pump basal rate. Four considerations underlie the rationale for reducing the dose to 2/3 rather than the subcutaneous rate:

• Differences in bioavailability and pharmacokinetics between IV infusion and subcutaneous infusion
• Patient’s NPO status
• Residual subcutaneous insulin at the infusion site of the insulin pump
• Patient safety, to err toward hyperglycemia rather than hypoglycemia, for the reason explained above.

If the patient has hyperglycemia (>180 mg/dL), an IV insulin infusion should be started and titration done according to the hospital algorithm. An example of such an algorithm is shown in Appendix A.

Four considerations underlie the rationale for disconnecting the insulin pump before all but short minor procedures and when there is no expected exposure to a ferromagnetic field (Table 2).

Patient Safety

Many clinicians are unfamiliar with this evolving technology; moreover, pumps are frequently upgraded and introduced to the market. Both facts might complicate in-servicing and educating clinicians on insulin pumps. However, a more important considera-
And often, warming devices like BearHugger comfort of OR personnel who have to wear sterile surgical gowns. In operating rooms, many operating rooms are kept on the cool side for the and patient temperature control is expected to be excellent in oper-

ation in patient safety is that substantial rates of pump failures have been reported, and complete failure in 44% of cases. Although in that report, the majority of patients did not experience serious adverse metabolic consequences [15], the U.S. Food and Drug Administration (FDA) announced that there had been an increase in problems with insulin pumps, in both their hardware and software, and many of these problems resulted in grave consequences [8].

Because insulin is temperature-sensitive, hot or cold environments may decrease its effectiveness [16]. For example, it has been reported that diabetic ketoacidosis developed from exposure of insulin pumps to heat and sunlight [17]. Although environmental and patient temperature control is expected to be excellent in operating rooms, many operating rooms are kept on the cool side for the comfort of OR personnel who have to wear sterile surgical gowns. And often, warming devices like BearHugger® are applied directly to patients.

Excessive sweating can occur during or after surgery, potentially dislodging the subcutaneous needle or catheter; and metal needles can cause irritation as a result of movement or contact [16].

Simplification of Glucose Control

Managing intraoperative glucose control is much simpler when insulin is administered only via the IV route, rather than subcutaneous along with IV. Additionally, patients on insulin pump therapy typically use faster-acting insulin analogs. Therefore any interruption in insulin delivery (due to mechanical obstruction, loss of integrity of the tubing, change in insulin potency, or pump malfunction) may result in hyperglycemia within 2 to 4 hours and subsequently the rapid development of diabetic ketoacidosis within 4 to 10 hours [18]. In such hyperglycemic circumstances, the increased production of ketone bodies is caused by severely low insulin concentration coupled with elevation in counterregulatory hormones, particularly epinephrine which causes activation of the hormone-sensitive lipase which in turn will cause the breakdown of triglycerides into glycerol and free fatty acids. Free fatty acids will eventually be oxidized into ketone bodies.

**Pump Manufacturers’ Recommendation**

Because of electro and ferromagnetic fields, the insulin infusion pump should be temporarily removed before the patient undergoes any radiologic procedure, such as magnetic resonance imaging, computed tomography, and X-rays. During such procedures, the insulin pump should be kept outside the imaging room [19]. This recommendation is advisable even though insulin pumps lack the lead mechanism found in cardiac pacers and defibrillators, which function as antennas for electromagnetic interference. Some of these pumps work on magneto-peristaltic systems, which must be deactivated before MRI [20].

**Pump Damage**

The pump can sustain potential damage from exposure to defibrillation or from cardioversion electroshock, such as during procedures in electrophysiology laboratories or during cardiac surgery. There is also the risk that the pump, tubing or cannula might be damaged or disconnected when a patient is moved from the cart to the operating room table.

**INTRAOPERATIVE MANAGEMENT**

At the authors’ institution, the IV insulin infusion algorithm described below is used for intraoperative glucose control in non-cardiac surgical patients. This algorithm is predicated on the validated algorithms utilized for intraoperative glucose control in the DeLiT trial [21]. It is inherently dynamic, and utilizes boluses and continuous infusion adjustments that differ for a given blood glu-

<table>
<thead>
<tr>
<th>Rationale for Discontinuation of Insulin Pump Intraoperatively</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mechanical Factors</strong></td>
</tr>
<tr>
<td>• Excessive sweating can dislodge the needle or catheter.</td>
</tr>
<tr>
<td>• Metal needles can cause irritation from movement or contact (minor influence).</td>
</tr>
<tr>
<td>• Possible risk exists of damaging or disconnecting the pump, tubing and/or cannula when the patient is moved or positioned on the operating room table.</td>
</tr>
<tr>
<td><strong>Physical Factors</strong></td>
</tr>
<tr>
<td>• There have been reports of pump damage as a result of direct exposure to heat. (Body warmers are commonly used intraoperatively.)</td>
</tr>
<tr>
<td>• Potential damage may occur to the pump from exposure to defibrillation or cardioversion electroshock.</td>
</tr>
<tr>
<td><strong>Technical Factors</strong></td>
</tr>
<tr>
<td>• Insulin pump failures have been reported in hardware and software.</td>
</tr>
<tr>
<td>• The insulin pump must be temporarily removed before any radiologic procedure such as magnetic resonance imaging, computed tomography, and X-rays. Ferromagnetic fields may potentially damage and/or alter the pump’s functionality.</td>
</tr>
<tr>
<td><strong>Pharmacologic Factors</strong></td>
</tr>
<tr>
<td>• Subcutaneous absorption of insulin is unreliable and may vary intraoperatively.</td>
</tr>
<tr>
<td>• Patients who use insulin pumps typically use faster-acting insulin analogs. Therefore, any interruption in insulin delivery may result in hyperglycemia within 2 to 4 hours.</td>
</tr>
<tr>
<td>• Insulin is temperature-sensitive, and it has been reported that diabetic ketoacidosis developed from exposure of the insulin pump to heat and sunlight.</td>
</tr>
<tr>
<td><strong>Medical personnel Factor</strong></td>
</tr>
<tr>
<td>• It is easier and probably safer to use one route, either intravenous or subcutaneous insulin infusion, for glucose control.</td>
</tr>
<tr>
<td>• Many clinicians are unfamiliar with this evolving technology and new pumps are frequently manufactured and marketed.</td>
</tr>
</tbody>
</table>
cose measurement depending on the delta change from prior measurement. Such a dynamic algorithm principle proved successful in achieving intended targets and in staying within target; and it also achieved low variability in blood glucose concentrations [22]. Most importantly, severe hypoglycemia (< 40 mg/dL) did not occur even with an intensive control target of 80–110 mg/dL. The dynamic nature of the algorithm accounts for the differences in Insulin sensitivity and intraoperative hyperglycemic stress response, as well as steroid-induced hyperglycemia, should the patient receive perioperative glucocorticoids [23]. While the DeLiT trial utilized two algorithms with two targets; intensive (80-100 mg/dL) versus conventional (180-200 mg/dL), more recent recommendations for intraoperative glycemic management call for a target range of 140–180 mg/dL. Interestingly, this target is similar to the one used for patients on insulin pumps (< 130 mg/dL, preprandial, and < 180 mg/dL random). Emerging evidence suggests that it may be beneficial to maintain glucose concentration close to the pre-admission values [24]. Our recommendation is in line with the AACE (American Association of Clinical Endocrinologists) and the ADA (American Diabetes Association) published consensus statement recommending < 180 mg/dL (10.0 mmol/L) as the desired target [25]. Their revised target glucose goal was predicated on the findings of the NICE-SUGAR Trial [26]. Moreover, clinicians are probably more likely to comply with a mildly to moderately tight target, such as the one proposed, rather than a very tight target. Intensive insulin protocols having more strict targets in cardiac surgery and critical care patients have historically been associated with a high incidence of hypoglycemia [26-29]. Anesthesiologists are understandably concerned about hypoglycemia because its signs and symptoms are masked by general anesthesia [30]. The same concern, along with more frequent glucose monitoring and changes in infusion rates, led to a reluctance of nursing staff to adhere to insulin infusion protocols targeting very tight glucose control [31, 32].

While most of the preceding discussion applies to all patients with diabetes, there is one situation that is specific to patients with T1DM. The traditional teaching regarding the management of these patients has been to continue insulin infusion even if glucose normalizes or dips into the hypoglycemic range. In such settings, a dextrose-containing solution is infused in order to maintain normoglycemia while the insulin infusion is continued at a low rate. This is particularly important for the treatment of diabetic ketoacidosis (DKA) and the correction of acidosis rather than hyperglycemia only. We have noticed that many clinicians follow this practice even in the absence of DKA. Due to the lack of rigorous evidence in support of this traditional approach, and the fact that fasting diabetic patients with hypoglycemia or normoglycemia rarely develop significant ketoacidosis; we believe that continuing insulin administration in the absence of keto-acidosis is not necessary. Furthermore, an association was observed between hospital and ICU mortality, on the one, and the amount of IV glucose administered, on the other [33]. Thus, in the absence of hypoglycemia, it is prudent not to administer IV glucose to fasting patients, - especially those at risk of developing stress hyperglycemia [34] - for the sole reason of maintaining insulin infusion. On the other hand, providing basal insulin in its long-acting subcutaneous form is crucial when discontinuing intravenous insulin infusion especially if the patient is to be monitored less often and the insulin pump is not reconnected promptly postoperatively because of the patient’s inability to safely resume self-management.

This discussion is geared toward perioperative glycemic management of diabetic patients using an insulin pump and undergoing noncardiac surgery. However, the insulin infusion algorithm would be slightly different for cardiac surgical patients in order to account for specific factors associated with cardiopulmonary bypass. The discussion of such concerns is beyond the scope of this review.

POST-ANESTHESIA CARE UNIT (PACU) MANAGEMENT

As the patient recovers from the anesthetic, the clinician should determine the appropriate time at which insulin management should revert to subcutaneous from continuous intravenous infusion. The clinician can make this decision through assessing the patient’s ability to self-manage and verifying the patient’s ability to continue using the insulin pump while in the hospital. It is also important to evaluate the impact of any sedatives and opiates which may be administered for pain control. The same intraoperative insulin infusion algorithm described above, with the same glucose concentration target, can be used in PACU/ICU while the patient remains cognitively or physically compromised.

A patient deemed competent can resume the routine presurgical target in the management of his or her own insulin pump. It might be reasonable to start the insulin pump 30 minutes before discontinuing the IV insulin infusion, to allow time for subcutaneous insulin absorption, the onset of action, and avoidance of fluctuations in glucose concentration. Once the patient is deemed sufficiently alert cognitively to resume using the pump, the patient should adhere to the protocols established for self-management of the insulin pump. In addition, the patient must agree to the hospital’s meter being the “Meter of Record” since the hospital’s meter has been tested against the laboratory findings and would therefore be the source of glucose results used to make adjustments in pump settings. Of particular note is the self-administration log that the patient uses to record carbohydrate consumption and bolus doses. The log should be shared with the bedside nurse at meal time and at bedtime. The patient should be instructed to alert the bedside nurse of any malfunction in delivery. If a malfunction occurs, the site should be changed if glucose >300mg/dL for 2 consecutive readings. An alternative source of insulin delivery should be considered if subsequent readings remain high after the insulin, reservoir and site have been changed. Glucose monitoring should be performed every hour until the glucose is <180mg/dL.

If the patient remains incompetent to manage the insulin pump postoperatively, the patient, or patient’s family, will have to be notified that the pump will be removed and that an alternative insulin regimen will be prescribed. Endocrinology staff can be of great assistance with insulin transition postoperatively. Appendix B summarizes two case studies for the perioperative management of patients using insulin pumps.

GLUCOSE MEASUREMENT:

There are many ways to determine glucose level: facility central laboratory or arterial blood gas analysis ( ABG machine) measure whole arterial or venous blood glucose; various point of care testing ( POCT) devices measure capillary blood glucose through direct skin puncture or whole arterial or venous blood sample; continuous glucometers measure glucose concentration in the interstitial fluid, and finally continuous in line glucometers, that measure whole blood glucose concentration through an indwelling arterial or central venous catheters are under development. Each method has its advantages and disadvantages. The POCT devices while quick and convenient, their accuracy has been scrutinized. The continuous interstitial fluid glucometer, while it provides continuous values, and is convenient, has the disadvantage of a lag period between blood and tissue glucose concentrations. Detailed discussion of this topic is beyond the scope of this manuscript. The reader is directed to a recent excellent review by Rice and Cousin [35] for more details. Generally speaking, when one methodology is used, ( such as POCT) the sampling site and the methodology should remain consistent throughout the procedure. In addition, blood glucose results should be verified using an alternate method e.g. ABG and/or central laboratory analysis when variations in blood glucose
results are $\geq 100\text{mg/dl}$ on consecutive blood samples, false lab results or contaminated specimen are suspected or when the glucose concentration value is nearing “critical values” and/or the POCT device displays a result of “HI” or “LOW”.

**CONCLUSION**

We recommend discontinuation of insulin pumps during the intraoperative and immediate postoperative periods in lengthy non-cardiac surgery and in procedures with expected X-Ray, MRI, and/or electric defibrillation exposure regardless of the duration of the procedure. A continuous IV insulin infusion should be used during long procedures. Frequent perioperative glucose monitoring is recommended to avoid both hyperglycemia and hypoglycemia. On the other hand, allowing a hospitalized patients to manage their own insulin pump postoperatively, if capable of doing so, is appropriate once they are cognitively alert to do so.

**CONFLICTS OF INTEREST**

None declared by any of the authors except Dr. Nasr: CME and Promotional speaker for Sanofi-Aventis

**Appendix A**

Intraoperative Glucose Control Protocol

The target range for blood glucose is 140–180 mg/dl.

- Discontinue all previous orders for insulin and oral glucose lowering agents.
- Must use infusion pump and run with maintenance fluid.
- Insulin concentration will be 1 unit of regular insulin/ml of normal saline
  - 50 ml of the insulin solution will be wasted when priming the tubing
- Blood glucose (BG) monitoring
  - Check BG in 30 minutes after starting the insulin infusion or after a bolus or change of infusion rate. BG may be checked at longer intervals (e.g., 60 min) if there was no intervention in the term of an insulin bolus or a change of infusion rate and if the concentration has been stable for two readings.
  - BG may be checked via ABG or bedside monitor. However, sampling site and lab analysis should remain consistent.
  - Verify BG results using an alternate method (e.g. finger stick) for:
    - Variations in BG lab results $\geq 100\text{mg/dl}$ on consecutive blood draws
    - Suspicion of false lab results or contaminated specimen
    - BG results reading “High” (>600 mg/dl) or “Low” (10 mg/dl) on the accu-check meter
- Calculation of insulin infusion change
  - If DECREASING RATE by 50%: New rate = Current rate $\times 0.5$
  - If DECREASING RATE by 25%: New rate = Current rate $\times 0.75$
  - If INCREASING RATE by 50%: New rate = Current rate $\times 1.5$
  - If INCREASING RATE by 25%: New rate = Current rate $\times 1.25$

**Initiation of insulin infusion**

(A less aggressive protocol may be indicated if the patient is known to be highly insulin-sensitive, ISF > 60 mg/dL)

<table>
<thead>
<tr>
<th>Blood Glucose (mg/dL)</th>
<th>Bolus- (IV)</th>
<th>Start Infusion At:</th>
</tr>
</thead>
<tbody>
<tr>
<td>181-200</td>
<td>2 units</td>
<td>2 units/hour, recheck in 1/2 hour</td>
</tr>
<tr>
<td>201-250</td>
<td>3 units</td>
<td>3 units/hour, recheck in 1/2 hour</td>
</tr>
<tr>
<td>251-300</td>
<td>4 units</td>
<td>4 units/hour, recheck in 1/2 hour</td>
</tr>
<tr>
<td>301-350</td>
<td>6 units</td>
<td>6 units/hour, recheck in 1/2 hour</td>
</tr>
<tr>
<td>$&gt;$350</td>
<td>7 units</td>
<td>8 units/hour, recheck in 1/2 hour</td>
</tr>
</tbody>
</table>

**How to adjust insulin infusions**

Please use the re-check glucose concentration (1/2 hour after the initial bolus and infusion as above) to identify the corresponding row in the table below. Choose the recommended next step from the column that corresponds to the amount of change in glucose concentrations from the prior value.
<table>
<thead>
<tr>
<th>Blood Glucose (mg/dL)</th>
<th>Decreasing Blood Glucose (↓ by more than 30mg/dL)</th>
<th>Stable Blood Glucose (No more than 30 mg/dL ↓ or ↑)</th>
<th>Increasing Blood Glucose (↑ by more than 30mg/dL)</th>
<th>Re-check in</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 70</td>
<td>Hold infusion, give 12.5-25ml dextrose 50%. Notify staff anesthesiologist</td>
<td>Hold infusion, give 12.5-25ml dextrose 50%. Notify staff anesthesiologist</td>
<td>Hold infusion, give 12.5-25ml dextrose 50%. Notify staff anesthesiologist</td>
<td>Immediately</td>
</tr>
<tr>
<td>71-140</td>
<td>Stop infusion</td>
<td>Stop infusion</td>
<td>Decrease the infusion by 50%</td>
<td>½ hour</td>
</tr>
<tr>
<td>141-180</td>
<td>Stop infusion</td>
<td>Continue same rate</td>
<td>increase rate by 25%*</td>
<td>½ hour</td>
</tr>
<tr>
<td>181-200</td>
<td>Decrease rate by 25%</td>
<td>Bolus 2 units I.V. and increase rate by 25%*</td>
<td>Bolus 2 units I.V. and increase rate by 25%*</td>
<td>½ hour</td>
</tr>
<tr>
<td>201-250</td>
<td>Continue same rate</td>
<td>Bolus 3 units I.V. and increase rate by 50%*</td>
<td>Bolus 3 units I.V. and increase rate by 50%*</td>
<td>½ hour</td>
</tr>
<tr>
<td>251-300</td>
<td>Bolus 3 units I.V. and continue same rate</td>
<td>Bolus 3 units I.V. and increase rate by 50%*</td>
<td>Bolus 4 units I.V. and increase rate by 50%*</td>
<td>½ hour</td>
</tr>
<tr>
<td>301-350</td>
<td>Bolus 4 units I.V. and continue same rate</td>
<td>Bolus 4 units I.V. and increase rate by 50%*</td>
<td>Bolus 5 units I.V. and increase rate by 50%*</td>
<td>½ hour</td>
</tr>
<tr>
<td>351-400</td>
<td>Bolus 5 units I.V. and continue same rate</td>
<td>Bolus 5 units I.V. and increase rate by 50%*</td>
<td>Bolus 7 units I.V. and increase rate by 50%*</td>
<td>½ hour</td>
</tr>
<tr>
<td>&gt;400</td>
<td>Bolus 7 units I.V. and continue same rate</td>
<td>Bolus 7 units I.V. and increase rate by 50%*</td>
<td>Bolus 10 units I.V. and increase rate by 50%*</td>
<td>½ hour</td>
</tr>
</tbody>
</table>

*Max. increase = 10 units/hr

1. The above recommendations are offered only as guidelines. Insulin infusions may require modification for certain patients, depending on clinical judgment and different clinical situations.
2. Round infusion rates to nearest 0.5 mL/hour.

Reprinted with permission, Cleveland Clinic Center for Medical Art & Photography © 2011-2012. All rights reserved.

Appendix B

CASE STUDIES ON MANAGING INSULIN PUMP PATIENTS PERIOPERATIVELY

Case 1:
CL, a 35-year-old engineer had had type 1 diabetes mellitus for 10 years. He had been using an insulin pump for 5 years. He was scheduled for 30-minute median nerve release at the carpal tunnel, out-patient surgery. His insulin pump settings were as follows:

**BASAL RATES:**
- 12 AM 0.80 units/hr
- 03 AM 1.35 units/hr
- 06 AM 0.90 unit/hr
- 12 PM 1.10 units/hr
- 06 PM 0.55 units/hr
- 09 PM 0.85 unit/hr
Carbohydrate ratio: 1/15

Insulin Sensitivity factor: 40 mg/dL.

His control had been tight: an HbA1c of 5.8% which is well below the current recommendation of <7% [25], which might explain why he experienced hypoglycemic symptoms at a glucose of 50-60 mg/dL once a week during exercise.

Preoperatively, his blood glucose concentration was 105 mg/dL. The procedure was very short with no planned or expected exposure to X-ray. In addition, no major blood loss, or fluid or temperature swings were anticipated. Moreover, the procedure was to be performed under Bier block using propofol induced moderate sedation, with an expected short recovery. Thus, a decision was made to continue the insulin pump at two-thirds of the basal rate perioperatively.

Case 2:

VR, a 56-year-old nurse, scheduled for radical nephrectomy, had had a history of T1DM for 25 years. She managed her diabetes with the use of an insulin pump for 12 years and her daily control had met the established target with an HbA1c of 7.1%. She had hypoglycemia unawareness and checked her glucose concentration 8-10 times a day. Her preoperative pump settings were as follows:

**BASEL RATES:**
- 6 AM 0.9 unit/hr
- 12 AM 0.4 unit/hr
- 3:30 AM 0.7 unit/hr
- 8 PM 0.8 unit/hr

**Carbohydrate ratio:** 1/20

**Sensitivity factor:** 60 mg/dL.

The need to discontinue the insulin pump and transition her to IV insulin was discussed with her. The transition occurred at 9 a.m. Her basal rate from 6 a.m. to noon ran at 0.9 unit/hr and therefore IV insulin would have been started at a rate of 0.6 unit/hr (2/3 of the usual rate); however, her blood glucose concentration was 284 mg/dL at the time of transition, which necessitated a bolus of 4 units of IV insulin, followed by an infusion rate of 4 units/hr; the blood glucose was monitored and maintained according to the algorithm (target 140-180 mg/dL). She was maintained on the insulin drip in PACU. Two hours postoperatively, the patient was deemed cognitively alert to manage her own insulin pump that she reconnected, and resumed pump infusion. IV insulin infusion was stopped approximately half an hour later.

**FINANCIAL SUPPORT**

Work was funded solely through internal departmental funds.

**ACKNOWLEDGEMENT**

The authors wish to thank Dr. Cecilia Lansang for her input in reviewing the insulin pump management chart.

**REFERENCES**


