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Diabetes management in spinal surgery

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Abstract

Diabetes mellitus can lead to long-standing complications in multiple arenas. An area that is often overlooked is implications for major surgery. Spinal decompression and fusions have unique challenges in the diabetic patient. In this review, we briefly highlight the pathophysiology of diabetes mellitus prior to examining implications for spinal surgery. We focus on the wound healing process, surgical infection risk, and delayed fusion. The paper then transitions to a focus on early diagnostics as well as pre-operative glucose control. Finally, we highlight important management strategies post operatively, continued necessity of monitoring, and emerging treatment and diagnostic approaches. This paper will serve as a key clinical guide that clinicians can utilize for diagnostic, management, and follow-up planning.

Keywords: Diabetes mellitus; Spine surgery; Management considerations; Diagnostics.

Introduction and significance

Diabetes Mellitus (DM) is known to be a leading cause of death in the US often as a result of cardiovascular and renal disease [1]. Studies show that approximately 642 million people worldwide will be diagnosed with DM by 2040, with an estimated prevalence of 10.4% [2]. Nearly 30% of adults aged 65 and older carry a diagnosis of DM [3]. It elevates the risk of end-organ damage, neuropathy, retinopathy, and nephropathy, in addition to its association with worse surgical outcomes.

As our society's population ages, spinal surgery will become more common as we observe a progressive rise in the diagnosis and management of degenerative spine diseases [4]. There are currently greater than one million spinal surgeries performed every year in the United States [5]. With an increasingly aging population, the need for spinal surgery as intervention for degenerative spine diseases will also reasonably increase. In a study investigating elective degenerative lumbar spine procedures performed between 2002 and 2011, it was found that a cohort of diabetic patients who had undergone surgery were significantly (P <.0001) older than patients who did not carry a DM diagnosis [6]. That same study also saw a significant (P<.0001) rise in the prevalence of diabetic patients over time. A study comparing spinal surgery patients without DM to those with DM, found that patients with Insulin-Dependent DM (IDDM) were significantly more likely to be older and to have multiple spinal levels fused [7]. There is a wealth of evidence that identifies DM as a risk factor for poor post-operative wound healing, spinal fusion rates, and surgical site infections [8-11]. These reports highlight the changing landscape of our population, the rising need for spinal surgery, and the importance of better understanding how to manage and care for diabetic spine surgery patients. Therefore, the aim of this review is to discuss the current literature and approach to management when caring for patients who carry a diagnosis of DM and require spine surgery.

Pathophysiology of diabetes

Diabetes mellitus (DM) describes a group of metabolic syndromes that are characterized by chronically elevated blood glucose concentration. Type 1 DM is the result of autoimmune mediated destruction of insulin producing beta cells in the pancreas, leading to absolute insulin deficiency [12]. Type 2 DM,

the most common form, is characterized by varying degrees of peripheral insulin resistance and impaired secretion from pancreatic beta cells [3,12]. Type 2 DM, in comparison to Type 1 DM, results in a relative insulin deficiency.

Diabetes disrupts normal wound healing

Normal wound healing is characterized by a complex process that can be divided into four stages which include hemostasis, inflammation, proliferation, and remodeling [13]. In hemostasis, platelet aggregation and local vasoconstriction of blood vessels result from release of inflammatory molecular mediators, later to be followed by vasodilation and vascular permeability. Release of transforming growth factor-beta and platelet-derived growth factor are involved in leukocyte chemotaxis to the site of injury [14]. The proliferative phase is hallmarked by substantial angiogenesis. Vascular endothelial growth factor, stimulated by local hypoxia, is pro-angiogenic, and directs vascular proliferation [15]. This process ultimately results in capillary pruning, stabilization by pericytes, and maturation of the vascular bed. Pericytesare recruited due to release of platelet-derived growth factor [16]. As the angiogenic response rages on, fibroblast migration and collagen synthesis lay the groundwork for dermal components needed for repair.

Wound healing has been shown to be impaired in diabetic patients [17,18]. In contrast to the normal healing process, DM results in an altered angiogenic state during wound healing. Michaels [19] and Trousdale [20] have previously reported that the diabetic mouse model, db/db had delayed excisional wound closure, less granulation tissue, and decreased neovascularization compared to non-diabetic control mice. DM has been shown to disrupt every stage of wound healing [15]. DM-associated changes include decreased response from pro-angiogenic stimuli such as hypoxia, miRNAmis regulation, and dysfunction in the production of anti-angiogenic mediators [15]. Also, dysfunction of macrophages, a known producer of vascular endothelial growth factor at the wound site have been cited as a contributing factor to diminished angiogenesis [21-23].

Diabetes associated with post-operative surgical site infections

Several reports have highlighted the role of DM and related comorbidities as a risk factor for surgical site infections after spinal instrumentation surgery [24,25]. Zhan et al [26] demonstrated from a retrospective cohort review of patients who underwent open lumbar posterior fusion surgery that diabetes (P=0.010) was a risk factor for an extended length of stay, placing patients at increased risk for serious complications such as infection (P=0.001). Koutsoumbelis [27] and Guzman [6] found that diabetic patients had an increased risk for postoperative infection following posterior lumbar instrumentation. Koutsoumbelis et al. conducted a retrospective study on 3218 adult patients who underwent lumbar/lumbosacral fusion via a posterior technique. 84 out of 3218 patients developed a surgical site infection. 17 of which had a medical history of DM, comprising 20.2% of the SSI cohort. They observed that DM was a risk factor for acquiring an infection with an odds ratio of 3.62 (1.61, 8.15, P=0.001).

In a retrospective study, it was found that surgical site infections were related to diabetes in complications requiring reoperation after posterior lumbar interbody fusion/transforaminal lumbar interbody fusion [28]. The authors used a prospectively maintained data base. The main indications for surgery in this study were either spondylolisthesis, canal stenosis, and disc herniation with foraminal stenosis. In a cohort of 1363 patients identified, a subset of 9 patients that required reoperation due to a surgical site infection were analyzed and compared to those that did not require reoperation. Of the 9 identified, 4 had a comorbid diagnosis of DM for a rate of 44.4% whereas those that did not require reoperation only had 14.7% of patients also diagnosed with DM. This difference was statistically significant (P<0.05). Although this cohort was limited by its smaller size, there are several other studies highlighting DM as a risk factor for developing surgical site infections. Similarly, Taree et al. highlighted that diabetes was an independent risk factor for 90-day readmission but not 30-day readmission [29]. This retrospective analysis identified 65,121 patients from the Healthcare Cost and Utilization Project Nationwide Readmissions Database who had undergone posterior lumbar fusion between 2012 and 2014 and required readmission. A subset of these patients who were being readmitted for surgical site infections were identified and compared to patients who required readmissions for another reason. They found that patients with uncomplicated diabetes comprised 25.4% of the surgical site infection readmission cohort compared to 13.5% in the non-surgical site infection group (P<0.0001).

Although there is overwhelming evidence in the literature indicating diabetes as a risk factor for SSI as a complication of spinal surgery, a study conducted by Freedman et al. found that despite DM being associated with more postoperative complications overall, it was not associated with a significantly greater incidence of infection [30]. This study compared a cohort of 199 patients with diabetes and 2226 patients without diabetes who had been enrolled in the Spine Patient Outcomes Research Trial (SPORT). Patients were enrolled for a diagnosis of intervertebral disc herniation, spinal stenosis, and degenerative spondylolisthesis. This is in contrast to a previous study reported by Simpson et al. [25] which found greater rates of wound infection in patients with a preoperative diagnosis of DM in either lumbar disc degeneration or spinal stenosis.

Despite the current evidence regarding DM and its association with post-surgical site infections, there still exists a paucity in the literature regarding differences in SSI ratesin spinal surgery outcomes comparing patients diagnosed with either Type 1 or Type 2 DM. General consensus of management of either type 1 or type 2 DM however has revolved mainly around maintaining euglycemic state and a pre-defined HgbA1C% score.

Decreased fusion rates in diabetic patients

There is evidence in the literature demonstrating that DM disrupts bone union following spinal manipulation [31]. Glassman et al [32] conducted a retrospective study examining 94 diabetic patients and 43 control patients who underwent posterior lumbar instrumentation. They identified 46 Non-Insulin Dependent DM (NIDDM), 35 Insulin-Dependent DM (IDDM), and 37 control patient who had follow-up beyond their 1-year postoperative visit. At follow up beyond one year, those with IDDM, NIDDM, and controls had a 26%, 22%, and 5% non-union rate, respectively. This study is one of few that compare fusion rates between NIDDM and IDDM patients undergoing spinal instrumentation. These results suggest perhaps IDDM may lead to worse outcomes which is unsurprising since patients with type 2 diabetes usually become insulin dependent after having

had diabetes for an extended period of time. However, the limited cohort size makes observed differences difficult to validate. A study conducted by Takahashi et al [33] with a larger cohort analyzed the demographic and clinical data of 41 patients with diabetes compared with 124 patients without diabetes who had undergone lumbar spine surgery. This study found similar complication rates between those with and without DM except for increased incidence of non-union after spinal fusion surgery in the diabetic cohort (20% vs 3%, P=0.095). Although several studies have previously reported DM and its association with decreased spinal fusion rates, they are largely limited to retrospective clinical studies with limited sample sizes.

Pre-operative evaluation of diabetic patient

Preoperative management and evaluation of patients presenting for surgery will focus mainly on cardiopulmonary risk assessment and how to best minimize chances of an adverse cardiopulmonary event intra or post-operatively [34]. This becomes particularly important in the diabetic patient as DM is a major risk factor for cardiovascular disease [35,36]. Patients who are being considered for spinal surgery require a careful history and physical examination. Baseline electrocardiogram, serum creatinine, and glycated hemoglobin, and blood glucose should be obtained. In addition to long-term complications of diabetes and length of diabetes diagnosis, it is important while attaining a history that the type of diabetes be elucidated. Type 1 and type 2 diabetes although often have similar outcomes have different pathophysiology and thus differ by methods of intervention to gain glycemic control. Patients with Type 1 diabetes must be managed with insulin where as those with Type 2 DM can be managed with lifestyle modifications, oral agents, non-insulin injectable agents, and/or insulin.

Utility of glycated hemoglobin (HgbA1C%) in pre-operative evaluation

Glycated hemoglobin is important in the assessment of overall glycemic control and risk for post-operative complications in spinal surgery patients as multiple studies have demonstrated that an elevated HgbA1C% is associated with an increased post-operative complication rate [37-42]. The American Diabetes Association (ADA) recommends that providers "perform an A1C test on all patients with diabetes or hyperglycemia (blood glucose >140 mg/dL [7.8 mmol/L]) admitted to the hospital if not performed in the prior 3 months" [43]. In a retrospective cohort study [44] examining 647 patients who underwent major noncardiac surgery, it was found that an HgbA1C% of greater than or equal to 7% had significantly greater association with infection risk (OR, 2.13; confidence interval, 1.23-3.70; P = .007). Similarly, a study examining 105 diabetic patients with spondylotic myelopathy who underwent laminoplasty showed that HgbA1C% levels >6.5% was a significant risk factor (odds ratio, 2.591; P =0.0193) for poor surgical outcome [45]. A study examining outcomes in diabetic patients showed that HgbA1C% levels above 6.1% were associated with elevated risk (AUC=0.77, 95%CI 0.70–0.84, P<.001) of failure to achieve clinical improvement for patients who had undergone anterior cervical fusion or posterior cervical laminectomy and fusion [46]. That same study found that HgbA1C% levels above 6.8% may also be associated with increased odds of requiring reoperation (AUC=0.61, 95%CI 0.52–0.69, P =.078). These studies suggest that the risk of negative outcomes may be increased in patients who present with a perioperative HgbA1C% level above 6%. Therefore, it is reasonable to consistently assess this before deciding to proceed with surgery and as a tool to measure likelihood of post-operative complications and overall outcomes.

Utility of blood glucose in pre-operative evaluation

Hyperglycemia is associated with worse surgical outcomes [38,47]. It has been reported that preoperative serum glucose level of >125 mg/dL in orthopedic surgery patients had an OR of 2.8 for development of a surgical site infection [48]. In support of this hypothesis, a study examining 3,184 patients who underwent non-cardiac surgery found that preoperative hyperglycemia was associated with significantly increased risk of adverse outcomes such as a prolonged hospital length of stay, mortality, bacteremia, and cardiovascular events [49]. Hyperglycemia has been shown to disrupt appropriate wound healing due to leukocyte dysregulation in the microenvironment [50], likely one of the many mechanisms behind increased surgical site infections and previously reported decreases in fusion rates.

Preoperative diabetes medication management

Diabetes management is a multi-factorial disease that often requires coordinated care from a multi-disciplinary approach for optimal outcomes. Patients who are found to have poor glycemic control on routine preoperative evaluation can benefit from interventions that achieve optimal HgbA1C% and blood glucose levels. Therefore, input from primary care doctors, endocrinology, and nutritional experts should be considered in an effort to attain comprehensive diabetic care and maintain tight glycemic control in surgical candidates. It is recommended by the American Diabetes Association (ADA) that providers consult with specialized DM or glucose management teams whenever possible in the hospital setting [43]. Providers should strive for glucose levels <200 mg/dL and HgbA1C%<7% [51]. Other studies have indicated that a blood glucose concentration <150 mg/dl should be the perioperative target [52,53]. Although achieving these targets for diabetic patients can take as much as 6 months to reach, once achieved the benefits are numerous.

Patients with DM should proceed to surgery as early in the morning as possible given that their nil per os status can place them at increased risk for a hypoglycemic episode. This becomes vitally important when the patient is a Type 1 diabetic who is completely insulin dependent. Carlsson et al [54] reported that nearly 70% of diabetic patients that undergo a major operation had hypoglycemic events where their blood glucose dipped below 70 mg/dL (3.9 mmol/L). There exists a limited amount of quality evidence regarding the best approach to perioperative blood glucose control in diabetic patients undergoing spinal surgery. However, it is strongly established that perioperative medication adjustments are important for preventing intra-operative and post-operative complications. Namely, hypoglycemia. The list below reviews the most common antidiabetic regimens that should be adjusted or held prior to surgery as well as their mechanism of action:

1. Sodium-Glucose Cotransporter 2 (SGLT2) inhibitors are a relatively new class of diabetes medications whose mode of action involveincreased elimination of serum glucose in urine by inhibiting reabsorption of glucose from glomerular filtrate. SGLT2 inhibitors are associated with ketoacidosis and should therefore be withheld a few days before surgery [55].

2. Metformin is an oral diabetic medication that decreases production of hepatic glucose and intestinal absorption of glucose. It also alters insulin sensitivity in the body for increased uptake and usage. Metformin is often the first-line medication

used to treat Type 2 DM. It is associated with lactic acidosis in those with renal impairment and should be withheld the morning prior to surgery.

3. Sulfonylureas act at the pancreatic beta-cell and stimulate insulin release [56]. They also work to decreased hepatic clearance of insulin [56]. It is associated with life threatening hypoglycemia in patients taking Cytochrome P450 2C9 inhibitors and patients with renal failure, or in states of fasting (e.g., nil per os status). Sulfonylureas and their analogues (Meglitinides) should be withheld the morning prior to surgery.

4. Thiazolidinediones work by decreasing storage of fatty acids in adipocytes, increasing glucose usage, and decreasing hepatic glucose production [57]. Due to their potential to cause heart failure and fluid overload. They should therefore be withheld the morning prior to surgery.

5. Dipeptidyl peptidase 4 (DPP-4) inhibitors and GLP-1 receptor agonistsincrease insulin secretion, decrease glucagon secretion, and delay gastric emptying through inhibition of GLP degradation and increased GLP-1 receptor activity [58]. It is associated with gastrointestinal motility disorders and therefore may lead to complications in the post-operative period. Given their low risk for hypoglycemia there is conflicting guidance as to whether they should be discontinued prior to surgery [59,60].

6. Insulin is a peptide hormone secreted by pancreatic beta cells works to regulate glucose absorption from blood for use by liver, skeletal muscle, adipose tissues, and other important bodily tissues [61]. In an effort to prevent ketoacidosis and other complications arising from hyperglycemia, basal insulin should be administered [62,63]. In a study conducted by Demma et al. that observed 150 patients with type 2 diabetes it was demonstrated that patients who took 60-87% of their normal insulin dose were more likely to achieve a target glucose range (P<.001) compared to patients who did not reduce their insulin dose the night before surgery [64]. Therefore, in an effort to prevent ketoacidosis but mitigate chances for hypoglycemia a modest reduction in normal insulin dose the night before surgery should be considered. Patients with continuous insulin infusion pumps are safe to maintain their normal basal infusion rate. Furthermore, patients with type 2 diabetes that will undergo longer operations should have their blood glucose measured every ~2 hours. Those who develop hyperglycemia may be treated intraoperatively with short/rapid-acting insulin solutions. Diabetic patients undergoing extended periods of surgery should be considered for IV insulin and glucose infusion for adequate intraoperative glycemic control [65,66].

Postoperative blood glucose management

Postoperative patients who have not yet awoken from surgery should have their blood glucose levels measured no less than every two hours. Management of blood glucose can be challenging given that during the postoperative period patients are at an increased risk for developing varying intensities of stress hyperglycemia. A maladaptive mechanism that results from an inflammatory state post-surgery which antagonizes insulin-mediated glucose uptake via excess cortisol [67]. In addition to hormonal changes, studies have implicated cytokines such as TNF-alpha and interleukin-1 in the dysregulation of insulin signaling [68,69]. Current literature discussing postoperative management of diabetes in patients who have undergone spinal surgery is limited. General principles from postoperative management of surgical patients should be applied with a target goal of <200 mg/dL (11.1 mmol/L) [70].

Timeline for restarting oral antidiabetic medications

Oral antidiabetic medications should not be restarted until the patient can tolerate a normal diet. Patients with Type 2 diabetes can be restarted on previously held oral antidiabetic medications as soon as they are able to tolerate a regular diet [71] who were treated with an intravenous insulin infusion should continue this regimen post-operatively until they are able to tolerate food, at which point the insulin infusion can be discontinued and replaced by an appropriate subcutaneous insulin agent. SGLT2 inhibitors are known to reduce sodium reabsorption in the nephron and thus may lead to hypovolemia. Therefore, these classes of medications should not be restarted in the in-patient setting [72]. Metformin however, due to its associated risk of adverse outcomes should not be restarted in surgical patients with impaired renal or hepatic function. Given that GLP-1 receptor agonists are associated with delayed gastric emptying, these agents should not be restarted to minimize the risk of vomiting. Thiazolidinediones have been shown to decrease bone production by inhibiting osteoblastogenesis with decreased mineralized tissue generation [73]. Although its utility in reducing blood glucose has been established, it may have negative effects on bone healing and the fusion process during recovery from spinal instrumentation. Sulfonylureas should be restarted at a low dose after patient only after patients has tolerated a regular diet and gradually advanced to preoperative dose.

Emerging alternatives to HgbA1C% for assessing glycemic control

Fructosamine is a glycated serum protein. Fructosamine measurements report glycemic control of the past 2 to 3 weeks as opposed to HgbA1C% which represents the past 3 months [74]. Shohat et al. 2017 [75] conducted a study investigating the role of fructosamine as a predictor of poor outcomes following total join arthroplasty. They reported that 64.7% of the high (≥292 µmol/L, N=51) fructosamine cohort had a history of DM compared to 11.1% in the low (<292 µmol/L, N=778) fructosamine cohort (P <.0001), suggesting at worst a moderate association between fructosamine and a diagnosis of DM. Furthermore, elevated levels of fructosamine were associated with greater infection rate (OR 3.1, 1 – 9.3), deep infections, and increased odds of readmission (OR 2.9, 1 – 7.9) [75]. There is limited evidence comparing utility of fructosamine and HgbA1C% in perioperative management of spine surgery however. Furthermore, there are previously reported studies that highlight difficulty in correlating fructosamine levels with HgbA1C% in obese patients [76]. More studies are required to determine its efficacy at assessing glycemic control perioperatively. Overall, there appears to be promise for the use of fructosamine as a valuable biomarker in assessment of glycemic control in the perioperative period.

Glycated Albumin (GA) has also emerged as a potential glycemic control biomarker for several reasons. GA is not altered by food intake, lifespan of erythrocyte, and can be used even in the presence of diseases such as hemoglobinopathies and iron deficiency anemia where HgbA1C% becomes less reliable [77]. In one study that compared GA to fructosamine and HgbA1C% in 150 subjects with type 1 and type 2 DM demonstrated that correlations of GA and mean blood glucose (Pearson correlation coefficient of 0.5902) were significantly greater (P< .001) than

that of correlations of fructosamine and mean blood glucose (Pearson correlation coefficient of 0.4540), supporting the role of GA is a potentially superior tool for assessing glycemic control than fructosamine [78]. A study by Ahmed et al demonstrated that GA may even be more sensitive than HgbA1C% [79].

Table 1: Common oral anti-diabetic agents and suggested perioperative adjustments summarized [55-60,64].

Oral antidiabetic agents	Mechanism of action	Common side effect profile	Pre-operative medication adjustment	Post-operative medication adjustment
Sodium-glucose cotransporter 2 (Canagliflozin, Empagliflozin, Dapagliflozin)	Reversibly inhibits SGLT-2 in the proximal tubule of the nephron leading to decreased glucose reabsorption	Hypovolemia Diabetic ketoacidosis Urinary tract/genital infections	Discontinue 2 to 3 days prior to surgery	Restart in the outpatient setting
Biguanide (Metformin)	Inhibits mitochondrial glycerophosphate dehydrogenase leading to decreased gluconeogenesis in the liver and absorption in the intestines Increases peripheral sensitivity to insulin	Lactic acidosis GI symptoms: nausea, vomiting, abdominal pain	Hold morning dose prior to surgery	Restart in the outpatient setting
Sulfonylurea/ Meglitinides (Chlorpropamide, Tolbutamide, Glyburide, Glimepiride)	Inactivation of ATP-sensitive potassium channels of B cells in pancreas leading to cell membrane depolarization that triggers insulin secretion through a calcium dependent mechanism Sensitizes peripheral tissues to insulin Decreases gluconeogenesis in the liver	Increased risk of severe hypoglycemia Granulocytopenia Hemolytic anemia Disulfiram-like reaction	Hold morning dose prior to surgery	Restart at low-dose after toleration of regular diet has been established
Thiazolidinediones (Rosiglitazone, Pioglitazone)	Activation of transcription factor peroxisome proliferator-activate receptor of gamma type resulting in increased gene transcription of genes important for glucose and lipid metabolism	Increased risk of bone fractures Fluid overload Increased risk of adverse cardiovascular event	Hold morning dose prior to surgery	Restart in outpatient setting. Consider an alternative agent given risk of osteoblastic dysfunction
Dipeptidyl peptidase 4 (DPP-4) inhibitors (Sitagliptin, Saxagliptin, Linagliptin) **GLP-1 receptor agonists** (Exenatide, Liraglutide, Albiglutide, Dulaglutide)	Incretin mimetics or inhibition of incretin degradation Promote glucose-dependent insulin secretion	GI symptoms: nausea, vomiting, early satiety, pancreatitis	Hold morning dose prior to surgery	Restart once patient is tolerating a regular diet to avoid risk of vomiting.

DM associated with reduced fusion in a murine model

A recent study investigated the hypothesis that DM and its alteration of the molecular microenvironment on the rate of fusion after spinal surgery. In an experimental animal study, 22 controls and 22 IDDM model rats who underwent posterolateral lumbar fusion surgery using a tailbone autograft were examined for consolidation and quality of formed fusion mass [31]. The study demonstrated that IDDM rats had lower spinal fusion rates as determined by manual palpation compared to those who were diabetes resistant (56.3% versus 16.7%, $P<0.05$). Furthermore, IDDM rats had reduced mean bone mineral density (448.2±43.5 vs. 519.1±44.4 HA/cm^3, $P<0.001$), bone volume (498.8±118.4 vs. 649.0±109.0 mm^3, $P<0.01$), and trabecular thickness (0.5±0.1 vs. 0.6±0.1 Tb. Th, $P<0.0001$) compared to controls when analyzed by micro-computed tomography. These results support the hypothesis that DM leads to clinically inferior fusion and quality of resultant bone post-operatively. Moreover, while this study found no differences in growth factors in the fusion bed between the two groups, they did find that proinflammatory markers (IL-1B, IL-5, IL-10, TNF-α, and KC/GRO) were significantly upregulated in the diabetic mice model. Previous studies have highlighted the role of proinflammatory cytokine, such as IL-1B in the inhibition of bone formation through dysregulated osteoblast function among other mechanisms [80-83].

Emergence of machine learning in predicting spine surgery outcomes

Machine learning and artificial intelligence is a rapidly expanding field that shows immense promise in almost every field of medicine. There are already multiple reports highlighting the value of artificial intelligence in predicting patient outcomes spanning oncology, neurosurgery, and general surgery [84-87]. Furthermore, there existseveral studies investigating the potential of machine learning in optimizing diabetes management [88-91]. Liu et al 2022 demonstrated that machine learning showed potential in accurately predicting the risk of surgical site infections in patients following lumbar spinal surgery. ML and AI can leverage the abundance of clinical data points and harness the power of dynamic computing to create impressive predictive models that may assist clinicians and neurosurgeons in making appropriate clinical decisions. Improved clinical decisions can span from better selection of candidates for surgery to improved insulin administration with hopes of better glycemic control perioperatively.

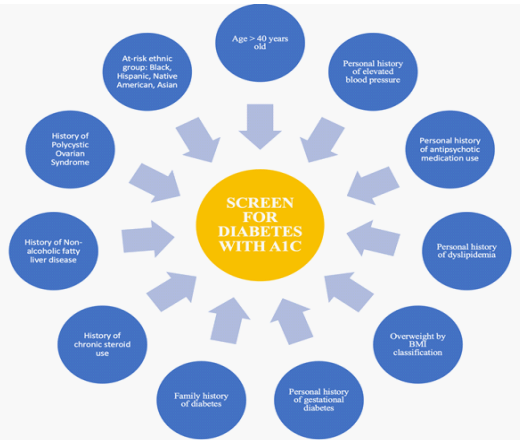

Figure 1: Summary of screening recommendations for patients who may have Type 2 diabetes [92,93].

Conclusion

DM is a group of diseases that lead to dysfunction in carbohydrate metabolism. It is a common disease that is growing in prevalence. As our society grows older the number of individuals who will require chronic blood sugar management will also increase. Moreover, with an increasing population comes a greater need for management of degenerative spine diseases. Many patients that neurosurgeons encounter for spine surgery may very well also carry a diagnosis of DM. This is of utmost importance because studies have shown DM to be associated with greater surgical risk due to an elevated incidence of adverse outcomes such as surgical site infections, pseudoarthrosis, diminished wound healing, increased readmission rates, and diminished clinical improvement. Although literature discussing diabetes management directly as it pertains to spine surgery patients is lacking, there is a strong body of knowledge regarding appropriate perioperative diabetes management [71]. The cornerstone of perioperative DM management center on adequate glycemic control and the mitigation of intra and post-operative complications such as hypoglycemia. Most DM patients should hold their dose of oral antidiabetic medications before surgery and can generally restart those medications once they are eating well. Most of the available literature is limited to retrospective cohort studies, but there are pre-clinical basic science models that highlight DM's role in disrupting normal healing, bone matrix formation and cytokine signaling. Better understanding of best practices in perioperative DM management and implementation of artificial intelligence-based clinical decision tools may help to improve outcomes of diabetic patients undergoing spinal surgery.

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