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The Economic Impact of Personalized Diabetes and Smoking Factors for Fusion Patients with Pseudarthrosis

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ABSTRACT

Spinal fusion surgery, a prevalent intervention for severe spinal conditions, often leads to significant clinical and economic challenges due to pseudarthrosis or nonunion of bones. Pseudarthrosis occurs in an average of over 30% of cases, causing persistent spinal instability and necessitating costly reoperations, with expenses reaching up to $60,000-100,000. This complication is exacerbated by patient-specific factors, notably smoking and non–insulin-dependent diabetes mellitus (NIDDM). Smoking impairs bone healing by reducing bone mineral density, osteoblastic activity, and local blood flow by 2.7 times a regular patient, while diabetes complicates surgical and healing processes with poor collagen, increasing the risk of nonunion. Advances in surgical materials and techniques, such as titanium alloy porous metal cages and recombinant human bone morphogenetic protein-2 (rhBMP-2), have aimed to improve outcomes, but success rates remain variable. Mitigating these risks involves comprehensive preoperative assessments and tailored interventions. Smoking cessation programs, nicotine replacement therapy (NRT), and strict diabetes management can significantly reduce pseudarthrosis rates. Future research should focus on the long-term efficacy and cost-effectiveness of such interventions and explore emerging technologies like robotic-assisted fusion surgery and advanced biomaterials. Policy-makers should allocate resources to preventive measures and ensure insurance coverage for advanced therapies to enhance patient outcomes and reduce financial burdens. Although these interventions incur varying costs, addressing both surgical and patient-dependent factors can minimize the incidence of pseudarthrosis, improving patient quality of life and potentially saving up to hundreds of millions in economic sustainability within the healthcare system.

Introduction

Spinal fusion surgery in orthopedics refers to the surgical procedure that aims to merge multiple spine segments into a single, continuous piece of bone. This procedure inherently results in a restriction of movement in the affected spinal region. Spinal fusion surgery is frequently performed, often as a last-resort intervention for spinal deformities, stabilization, or the alleviation of chronic pain. Despite its prevalence, this surgery has significant costs and variable outcomes. Notably, for average patients, more than 68% of fusion surgeries are successful, 2% result in infection, and the remaining 30% result in pseudarthrosis, or nonunion of the bones, where the intended solidification of the vertebrae fails, leading to persistent movement and instability in the spine (Larsen et al., 1997). This is much less to say that pseudarthrosis can come with additional complications such as infection and neuropathic pain.

The economic ramifications of pseudarthrosis are substantial. When a fusion surgery fails, additional interventions, such as prolonged physical therapy or repeat surgeries, may be required to address the nonunion. The cost of these additional treatments can escalate to as much as $60,000-100,000 (Hansson-Hedblom et al., 2019). Clinically, signs of pseudarthrosis can manifest as early as six weeks postoperatively and include persistent pain, spinal instability, and neurological symptoms such as numbness. These symptoms are confirmed through physical examinations and imaging techniques, including X-rays, CT scans, and MRIs (Philipp et al, 2021).

The development of pseudarthrosis can be attributed to a variety of factors. Surgical factors include improper technique, inadequate blood supply to the fusion site, insufficient postoperative activity restriction, and infection (Larsen et al, 1997). More significant contributors include hardware failures, such as spinal implants' incompatibility or poor performance, and inadequate bone grafting (Oliveira et al., 2017). Over the past two decades, advances in surgical materials and techniques have aimed to address these issues. For instance, the use of titanium alloy (Ti-6Al-4V) porous metal cage devices has been shown to enhance osteoconductive and osteoinductive properties as well as osteogenesis shown in Figure 1 which promote the activity of bone morphogenetic proteins (BMPs), vascular endothelial growth factor (VEGF), interleukins (IL), and osteocalcin, thereby mitigating hardware performance issues (Olivares-Navarrete et al., 2012).

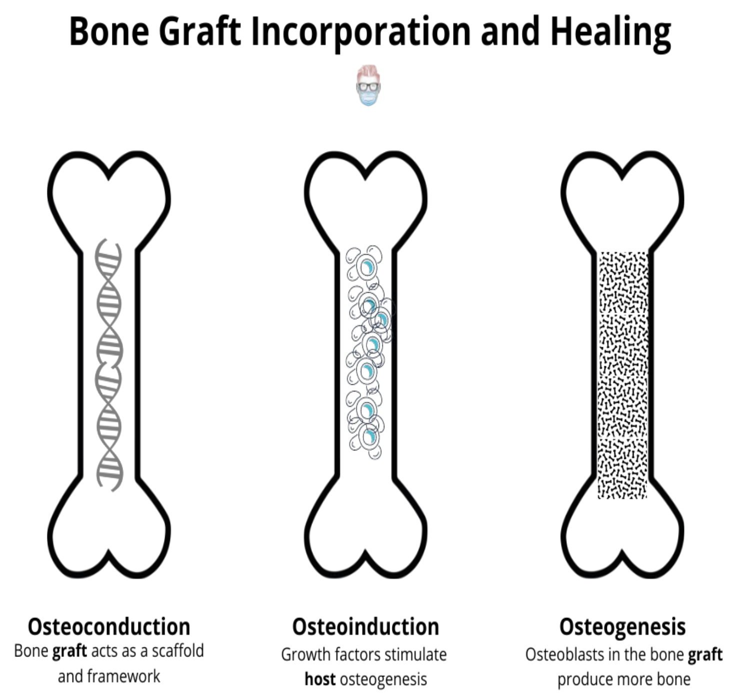

Figure 1. Osteoinduction vs Osteoconduction vs Osteogenesis
Source: https://www.theplasticsfella.com/bone-grafts/

While surgical technique and hardware improvements have been well-studied, patient-dependent factors have received less attention. Conditions such as smoking and diabetes are known to affect bone healing and fusion success rates adversely. The factors of smoking and diabetes have also been shown to be the leading personal factors contributing significantly to the incidence of pseudarthrosis. This paper aims to explore the impact of these patient-dependent factors on the development of pseudarthrosis, examine why these issues have persisted despite advancements in other areas, and identify potential methods to address these challenges without incurring significant economic burdens.

Addressing pseudarthrosis requires a comprehensive understanding of both surgical and patient-dependent factors. While significant strides have been made in improving surgical techniques and materials, further research is needed to mitigate the effects of patient-specific factors such as smoking and diabetes, especially in the US. This paper aims to shed light on these persistent issues and propose viable solutions to enhance the outcomes of spinal fusion surgeries, thereby reducing the incidence of pseudarthrosis and its associated economic impact.

Fusion Surgery: Reasons and Types

Spinal fusion surgery is necessitated by various spinal pathologies, primarily including degenerative disc disease (DDD), spondylolisthesis, spinal stenosis, disc herniation, severe scoliosis, and spinal fractures as well as overall spinal infection and neoplasm (Oliveira et al., 2017). Up to 80-85% of the world's population experience intense back pain, especially in the lower area in their lifetime (Hansson-Hedblom et al., 2019). Degenerative disc disease involves the deterioration of intervertebral discs, leading to pain and spinal instability (Oliveira et al., 2017). Spondylolisthesis, characterized by one vertebra slipping over another, similarly results in instability and pain. Spinal stenosis and disc herniation, which cause spinal canal narrowing, exert pressure on the spinal cord or nerves. Severe scoliosis, a significant curvature of the spine, requires correction and stabilization, while spinal fractures due to trauma or osteoporosis necessitate stabilization for proper healing.

Causes of Spinal Instability

Unstable vertebrae can experience excessive stress, leading to cracks or compression of the spinal cord, which can cause permanent nerve damage. Factors contributing to this instability include years of strenuous physical labor, physical pressure from body weight, sudden impacts such as car crashes, and congenital disabilities (Felman, 2023). These factors contribute to the deterioration of intervertebral discs, which lose their gel-like cushioning function over time and spinal deformity. Consequently, spinal health issues are prevalent among the elderly and those with genetic predispositions, which require the most fusion surgery. Furthermore, although spinal fusion can limit spinal movement, it also mitigates pain and instability, making it a viable option when other treatments fail. Initial treatments typically include pain medication, steroids, and physical therapy (Felman, 2023). However, when these interventions are insufficient, fusion surgery becomes a last-resort treatment. Spinal fusions are most commonly performed in the lower lumbar region, particularly at L4-5 or L5-S1, due to the high mechanical stress and weight-bearing demands in these areas by 147 of 166 (89%) (Kazberouk et al., 2016).

Evolution of Spinal Fusion Techniques

The first spinal fusion was performed in 1909 by Dr. Fritz Lange on a scoliosis patient using basic metal wires and a steel intervertebral implant (Virk et al., 2020). Since then, advancements in materials and surgical techniques have significantly evolved. Fusion surgeries can be approached posteriorly or anteriorly, depending on the specific circumstances. Fusion surgery offers several techniques to stabilize the spine and alleviate symptoms associated with various spinal conditions. These are all assisted with bone grafts, which are usually made from bone from the tibia but can also be allogeneic and are placed in certain areas to encourage the rebuilding, or in this case, the formation of bony bridging between the two vertebrates to solidify the fusion (Virk et al., 2020).

One standard method is posterolateral fusion (PLF), where a bone graft is placed between the transverse processes of the vertebrae, typically approached from the back of the spine (Larsen et al., 1997). Alternatively, interbody fusion involves placing a bone graft or a cage between the vertebrae through different approaches, such as anterior lumbar interbody fusion (ALIF), posterior lumbar interbody fusion (PLIF), or transforaminal lumbar interbody fusion (TLIF). Anterior cervical discectomy and fusion (ACDF) address cervical disc issues through a front-neck approach, while posterior cervical fusion targets cervical instability or deformity from the back of the neck (Philipp et al., 2021). Combined anterior/posterior cervical fusion may be necessary for more complex cervical spine conditions. In addition, lateral lumbar interbody fusion (LLIF) offers a minimally invasive lateral approach to the lumbar spine, while minimally invasive fusion techniques like MIS TLIF and MIS LLIF aim to reduce tissue damage and expedite recovery (Larsen et al., 1997). Robotic-assisted fusion surgery is also emerging, aiding surgeons in performing fusion procedures with enhanced precision (Philipp et al., 2021). The choice of fusion technique depends on factors such as the specific spinal condition, patient anatomy, and surgeon expertise, ensuring tailored treatment for each individual, as shown in Figure 2.

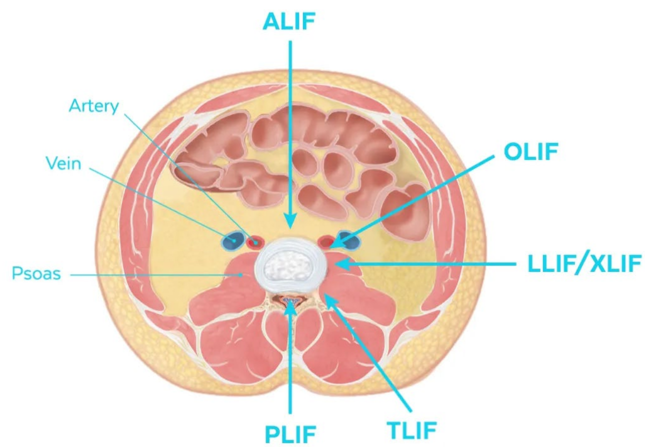

Figure 2. All Types of Locations to Enter for Lumbar Interbody Fusion
Source: https://selliliar.live/product_details/29412579.html

Economic Considerations of Spinal Fusion Surgery

Spinal fusion is considered a last resort not only due to its invasive nature but also its substantial cost. Annually, approximately $90 billion is spent on medical expenses related to low back pain in the United States, with spinal fusions alone accounting for $13 billion, where the volume of spinal fusions increased 2.4-fold between 1988 and 2008 (Kazberouk et al., 2016). So despite 1.2% of back pain leading to surgery, back pain contributes to 30% of total US healthcare expenditure alongside runner-ups with heart problems and diabetes (Philipp et al., 2021). The cost of these procedures varies significantly: Anterior and posterior lumbar/lumbosacral fusion procedures are the most costly, with a median cost of $27,944, Posterior lumbar decompression and fusion (interbody fusion) has a median cost of $14,037, Anterior cervical discectomy and fusion incurs a median cost of $7,098, Posterior laminectomy has a median cost of $4,292, Lumbar discectomy has a median cost of $2,967 (Kazberouk et al., 2016). These costs include anesthesia, intensive care, inpatient stays, laboratories, operating room expenses, post-anesthesia care, pharmacy, preoperative care, radiology, and supplies/instrumentation. Supply costs alone weighed 61%.

However, it's also to be noted that on the high end, surgery could also go for more than $130,000 (specifically $129,220). Spinal fusion surgery remains a critical intervention for addressing severe spinal conditions when other treatments fail. Despite its high cost and the potential for complications such as pseudarthrosis, advances in surgical techniques and materials continue to improve patient outcomes. Understanding the economic impact and the necessity of tailored approaches based on individual patient factors and specific spinal conditions is essential for optimizing treatment and mitigating the financial burden of spinal fusion surgeries.

Pseudarthrosis: Causes and Effects

Postoperatively, pseudarthrosis is the leading cause of failure in fusion surgery. Pseudarthrosis, or "false joint," occurs when bone healing fails following a fracture or surgical fusion, resulting in a nonunion where the bone ends do not join as expected, as depicted in Figure 3. This condition can lead to persistent pain, instability, and abnormal movement at the nonunion site, mimicking joint motion. Pseudarthrosis can arise from inadequate stabilization, insufficient blood supply, infection, or other factors that impair routine bone healing. Over 32% of patients, 81% in the worst-case scenario, who undergo spinal fusion experience incomplete or unsuccessful fusion, leading to pseudarthrosis (Larsen et al., 1997).

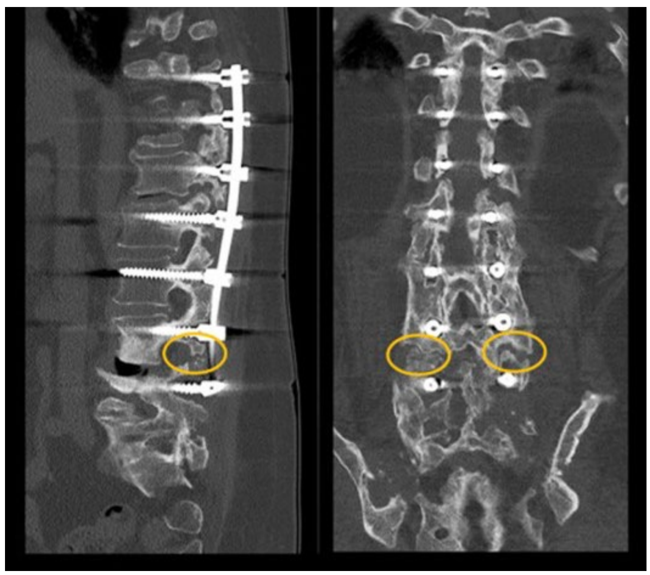

Figure 3. Lateral and Coronal Views of Pseudarthrosis
Source: https://www.nassopenaccess.org/article/S2666-5484%2822%2900075-0/fulltext

Surgical Techniques for Pseudarthrosis Repair

Repairing pseudarthrosis is both costly and challenging, often with limited success. The surgical treatment of pseudarthrosis varies significantly depending on the clinical situation, and a comprehensive description of all possible surgical techniques exceeds the scope of this review. Generally, rigid internal fixation is applied across the affected motion segments for nonunion of posterolateral fusion without fixation, supplemented with additional long interposition graft material (Larsen et al., 1997). Pedicle-screw instrumentation and autologous bone graft are preferred when possible, with alternative graft options considered only after exhausting autologous donor sites.

The adequacy of existing posterior fixation in providing immobilization across the pseudarthrosis must be assessed. Loose or broken fixation should be repaired, followed by regrafting the area. In some cases, it may be necessary to remove the fixation and regraft the nonunion site, combined with electrical stimulation and bracing. Anterior lumbar interbody fusion (ALIF) is recommended if posterior procedures fail to achieve solid bone union. ALIF can be performed concurrently with a posterior procedure or as a second-stage operation if needed.

For primary posterior lumbar interbody fusion (PLIF), the indication is for posterolateral fusion with rigid internal fixation in cases of pseudarthrosis. If both PLIF and posterolateral fusion with internal fixation were initially performed and failed, the protocol for failed posterolateral fusion should be followed. In cases of failed primary anterior interbody fusion, the initial attempt to address the issue is typically posterior, requiring rigid posterior segmental fixation and bone grafting in the posterolateral gutter. Revision anterior grafting may be necessary, with careful dissection to avoid damage to anterior structures. Anterior fixation should be considered in cases of encountered instability.

Economic Burden of Pseudarthrosis Repair

Regardless, these additional procedures on top of the original fusion are very costly. Statistical analysis found that reoperation tends to cost an average of $14,037, which may exceed 100% of the cost of the original surgery (Kazberouk et al., 2016) plus additional medication, hospitalization, and therapy can lead the cost to $60,000-100,000 (Hansson-Hedblom et al., 2019). Furthermore, successful functional outcomes in only 27% of patients after pseudarthrosis repair (Carpenter et al., 1996). An already weakened bone is harder to heal upon revisitation, compounding the challenges associated with treating pseudarthrosis effectively. Pseudarthrosis remains a significant complication in spinal fusion surgery, posing both clinical and economic challenges. Despite advancements in surgical techniques and materials, the success rates of pseudarthrosis repair are limited, and the costs are substantial.

Demographic Personalized Factors to Pseudarthrosis

Many factors contribute to pseudarthrosis. This includes external material factors such as the bone graft as well as cages specifically for an interbody fusion where they have been modified with different types of metal alloys, like the Ti, and characteristics to enhance the osteogenesis and osteoconductive environments of bone cells via BMPs, VEGFs, ILs, osteocalcin, etc (Olivares-Navarrete et al., 2012). There are also personal factors such as talar avascular necrosis, history of open fracture or infection, chronic steroid use, rheumatoid arthritis, inadequate fixation, and neuropathy which all lead to similar increased nonunion (Ishikawa et al., 2002). However, the leading popular cause of pseudarthrosis caused by the patients personally are those who smoke or have diabetes, especially Type 2 Non–Insulin-Dependent Diabetes Mellitus (NIDDM). These patients are more vulnerable to more frequent long-lasting pain and financial drainage from the recovery and re-operative measures taken from pseudarthrosis and it’s imperative to know why.

Impact of Smoking on Pseudarthrosis

Smoking is a leading patient-specific cause of pseudarthrosis. An estimated 42.1 million cigarette smokers in the United States contribute to 480,000 deaths annually, making smoking a significant public health issue (Jackson et al. 2016). Theoretically, an individual in the US of roughly 330 million people, who has an 85% chance of developing back pain, about 1.2% requiring fusion surgery, and an approximately average scenario of 32% of these cases result in pseudarthrosis is just less than 1 in 300 people as one million people would have this issue. But if an individual smokes, the chances are tripled or even quadrupled giving one a chance of painstaking recovery process post-pseudarthrosis a 1 in 75 chance. This means, that of the 42.1 million smokers in the US, just over 500,000 theoretically when it should have been around 130,000. In one study by Ishikawa et al. in

2002 found that among 148 fusion surgery patients, 27% were smokers. Nonsmokers had a nonunion rate of 7.1%, whereas smokers had a nonunion rate of 18.6%, indicating that smokers are 2.7 times more likely to experience nonunion (p=0.04). Former smokers also showed higher nonunion rates of 11.1%. This increased risk is not limited to spinal fusion; for instance, smokers undergoing ankle arthrodesis have a 3.75 times higher risk of nonunion compared to nonsmokers.

In another study done by Seicean et al. in 2013, of 14,500 patients undergoing elective spine surgery, 27.0% were current smokers, and 14.2% were prior smokers. Former smokers were 110-160% more likely to experience prolonged hospitalization and major complications compared to those who never smoked. Additionally, within 30 days post-surgery, current smokers with a history of more than 60 pack-years had an 80% higher likelihood of dying compared to non-smokers.

Smoking increases the risk of pseudarthrosis through several mechanisms, including decreased systemic bone mineral density, reduced osteoblastic cellular metabolism, and impaired local blood flow and angiogenesis, particularly in lumbar and cervical fusions (Jackson et al. 2016). Decreased blood flow to the disk tissue or vertebral segments during the fusion process significantly impacts healing. Tobacco use also reduces tissue oxygenation, impairs inflammatory cell function, and inhibits reparative cell activities, such as cytokine production, osteoinductive protein synthesis, and extracellular matrix formation. Additionally, smoking can cause osteoporosis, increasing vertebral and endplate porosity and decreasing trabecular thickness (Berman et al. 2017). Smoking influences various physiological processes, including increased cortisol levels, estrogen imbalance, osteoblast depletion, calcitonin inhibition, decreased oxygen supply, and reduced calcium absorption, leading to increased bone resorption and decreased bone formation.

The healing process in spinal fusion follows a similar pattern to secondary bone healing in long bone fractures, involving inflammatory, repair, and remodeling stages (Berman et al. 2017). Smoking adversely affects fusion healing, particularly during the repair stage, by inhibiting angiogenesis and disrupting collagen matrix and soft callus formation. Although posterior cervical fusions with lateral mass instrumentation and iliac crest autograft might not be affected by smoking, cases using local autograft which is less rich in bone marrow and osteogenic cells, compared to above, may experience reduced fusion rates because osteogenesis, osteoconduction, and osteoinduction properties, are hindered by smoking. Nicotine in cigarettes affects the expression of crucial proteins like BMPs, transforming growth factors (TGF-β), basic fibroblast growth factor (bFGF), and VEGF, impairing vascularization and nutrient delivery. It also decreases collagen production, compromising the mechanical strength of the fusion mass and increasing the risk of nonunion. Smoking increases the risk of surgical site infection, delayed wound healing, and perioperative complications, particularly in anterior cervical corpectomy (Jackson et al. 2016). Decreased tissue oxygenation, impaired immune function, and microvascular disease contribute to higher complication rates (Berman et al. 2017). Smokers also face a higher risk of adjacent-segment pathology and dysphagia post-ACDF due to increased disc degeneration and vertebral bone weakness.

Impact of Diabetes on Pseudarthrosis

Complications Associated with NIDDM

Patients with non–insulin-dependent diabetes mellitus (NIDDM) or Type 2 Diabetes face an increased risk of developing pseudarthrosis following spinal fusion surgery. NIDDM has been historically associated with frequent, long-lasting pain and significant financial burdens due to the need for extended recovery and potential re-operative measures. In a 1990 study, Kardaun et al. utilized data from the National Hospital Discharge Survey to assess acute complication rates in patients with lumbar disc herniation (LDH) to address the complications associated with NIDDM. The study included 3,289 surgically treated and 4,025 nonoperative LDH patients. The findings indicated that patients with obesity, hypertension, and diabetes had surgical complication rates three to four times higher than standard patients following lumbar discectomy.

Later, in 2003, Researchers Cohen et al. identified diabetes as a significant risk factor for intradiscal electrothermal therapy (IDET) failure; among 69 non-obese patients, 37 (54%) achieved positive outcomes with IDET. However, only one of the ten obese patients experienced a positive outcome (P = 0.01). Notably, 2 of the ten obese patients were diabetic and developed complications, resulting in worsening disc conditions. Despite the small sample size of diabetic patients, these findings highlighted the potential impact of diabetes on spinal surgery outcomes.

Additionally, in 2009, Pull ter Gunne found an increased rate of deep surgical site infections (SSI) among diabetic, obese, and patients undergoing longer surgical procedures. Of the 3,174 orthopedic spinal surgery patients, the study found that 132 (4.2%) developed SSIs, with 84 experiencing deep infections. Diabetes (P = 0.050) was identified as an independent, statistically significant risk factor for deep SSIs. Both Cohen et al. and Pull ter Gunne concluded that diabetic patients are at higher risk for complications such as infection and disc damage, leading to increased rates of nonunion after spinal fusion surgeries.

Pathophysiology and Complications of Pseudarthrosis in Diabetic Patients

Diabetes may increase the risk of pseudarthrosis due to impaired bone healing and metabolic dysfunction. Reduced blood flow and poor collagen production weaken the delivery of needed nutrients and the formation of the bone matrix, crucial for healing. Additionally, the weakened immune response and chronic inflammation associated with diabetes can delay recovery and elevate infection risks. High blood sugar levels contribute to the accumulation of advanced glycation end products (AGEs), which disrupt normal bone remodeling. Furthermore, diabetes impairs osteoblast function, reduces bone formation, and can cause nutrient absorption issues, leading to deficiencies in essential vitamins and minerals necessary for bone repair. Collectively, these factors impede the bone healing process, increasing the likelihood of pseudarthrosis.

In 2008, Boakye et al. reported a fourfold increase in mortality rates among insulin-dependent diabetes mellitus (IDDM) patients compared to non-diabetic patients, indicating a significant impact even though the study focused on IDDM. Additionally, Veeravagu et al. in 2009 identified IDDM as a risk factor for postoperative spinal wound infections.

For NIDDM patients, Glassman et al. (2007) reported higher complications such as nonunion rates post-lumbar instrumentation and fusion. An earlier study by Glassman et al. (2003) found that both IDDM and NIDDM patients had higher complication rates than controls (non-diabetic), with IDDM patients experiencing more major complications and NIDDM patients encountering more minor complications. This study included 94 diabetic patients and 43 controls, revealing a statistically significant difference in both minor and major complication rates when comparing the NIDDM group to controls (P = 0.001). The control group had a total complication rate of 21%, whereas the NIDDM group had a complication rate of 53%.

Economic Impact to Mitigating Smoking and NIDDM Factors of Pseudarthrosis

Mitigating Smoking-Related Risks

Smoking cessation should be strongly advised during critical periods of angiogenesis (the first 3-4 weeks) and bone healing (the first 6 months) following spinal fusion surgery. To mitigate the adverse effects of smoking on fusion healing, the use of osteoinductive bone proteins such as recombinant human bone morphogenetic protein-2 (rhBMP-2) combined with autogenous bone may be beneficial (Oliveira et al., 2017). The induction of osteogenic and angiogenic cytokines by osteogenic protein-1 (OP-1) may also be a seeming possibility. Additionally, nicotine replacement therapy (NRT), including e-cigarettes, patches, gum, and medications like Varenicline, can potentially reduce the detrimental impacts of smoking on bone healing (Berman et al., 2017).

Nicotine alone may stimulate bone metabolic activity, whereas other components of cigarette smoke are more harmful to the healing process. NRT, though cost-effective (ranging from $45-100 per two-week session), does not entirely eliminate the risk of pseudarthrosis compared to smoking cessation therapy, which is more expensive ($100-400 per session) but still a valid treatment (Berman et al., 2017). Conversely, BMP therapy is the most expensive option, costing up to $10,000, but it significantly reduces the likelihood of pseudarthrosis, thereby potentially avoiding the need for reoperation, which can reach up to $60,000-100,000 (Oliveira et al., 2017). The financial implications are considerable; for every 1% reduction in smoking-related factors, an estimated average of $398 million could theoretically be saved.

Mitigating Risks in Diabetic Patients

For patients with non–non-insulin-dependent diabetes mellitus (NIDDM), effective management of their condition can significantly reduce the risk of pseudarthrosis following spinal fusion surgery. A study by Cho et al. (2012) indicated that patients with well-controlled NIDDM did not face increased risks for perioperative complications or additional surgeries. This finding suggests that proper diabetes management can completely mitigate the risk of pseudarthrosis associated with NIDDM. The financial benefits of such management are substantial; for every 1% reduction in poorly managed diabetes-related factors, approximately $299 million could be saved.

In comparison, a study by Cook et al. (2008) discovered that patients with uncontrolled diabetes mellitus (DM) experienced higher perioperative complications than controlled DM post-cervical fusion. The study analyzed 37,732 patients diagnosed with cervical spine myelopathy (CSM) who underwent cervical spine fusion between 1988 and 2004 where 3,432 patients had a diagnosis of DM. The DM group was significantly older, male-sided, and more likely from Black or Hispanic descent ($P < 0.01$). Additionally, these patients had significantly more levels of bone fused compared to non-DM patients. And the analysis of perioperative outcomes revealed significant differences between diabetic and nondiabetic patients. Diabetic patients were more likely to experience respiratory or cardiac complications, peripheral vascular complications, hematomas or bleeding, transfusions, and dysphagia (all $P < 0.001$). Most importantly though, comparisons between uncontrolled and controlled DM showed that patients with uncontrolled DM were more likely to have cardiac complications, hematomas, nonroutine discharges, longer lengths of stay (all $P < 0.001$), and higher total inflation-adjusted hospitalization charges ($P = 0.004$).

These findings align with Cho et al.'s research, which underscores that controlled diabetes significantly decreases the chances of postoperative failure. Therefore, it is crucial for individuals with NIDDM to adhere to their treatment plans and medication regimens. By maintaining a healthy track, they can significantly reduce the risk of pseudarthrosis and other complications, leading to better surgical outcomes and reduced healthcare costs.

Conclusion

Spinal fusion surgery, though often necessary for addressing severe spinal conditions, carries significant risks, with pseudarthrosis being a prominent complication affecting over 30% of patients. This nonunion of bones results in persistent movement and instability, necessitating further medical interventions. The economic impact of pseudarthrosis is substantial, with reoperation costs reaching up to $60,000, doubling the financial burden of the initial surgery. Smoking and non–insulin-dependent diabetes mellitus (NIDDM) are major patient-dependent factors contributing to the high incidence of pseudarthrosis. Smoking impairs bone healing by reducing bone mineral density, osteoblastic activity, and local blood flow, while diabetes complicates surgical and healing processes, increasing the risk of nonunion. Despite advancements in surgical techniques and materials, such as the use of titanium alloy porous metal cages and rhBMP-2, the success rates of spinal fusion surgeries remain variable. Patient-specific interventions, including smoking cessation, nicotine replacement therapy (NRT), and strict diabetes management, have shown potential in reducing pseudarthrosis rates. However, these interventions come with varying costs and effectiveness, necessitating a balanced approach to optimize patient outcomes while managing economic burdens.

Future research should focus on long-term studies to evaluate the efficacy and cost-effectiveness of interventions such as BMP therapy, NRT, and comprehensive smoking cessation programs. Personalized treatment plans for patients with NIDDM undergoing spinal fusion should be further explored to enhance surgical outcomes. Additionally, the impact of emerging technologies like robotic-assisted fusion surgery and advanced biomaterials on reducing pseudarthrosis should be investigated. Research into genetic predispositions and lifestyle influences on spinal fusion outcomes could provide deeper insights into personalized treatment approaches. Further exploration of novel pharmacological agents and biologics in improving fusion success rates is also warranted.

Clinical practice should prioritize comprehensive preoperative assessments and tailored interventions for patients with known risk factors. Smoking cessation programs, supported by NRT and other therapies, should be emphasized, and strict management of NIDDM should be advocated. Policy-makers should allocate resources to fund and promote preventive measures, recognizing their potential to save hundreds of millions in healthcare costs by reducing pseudarthrosis rates. Insurance coverage policies should be evaluated to ensure access to advanced therapies like BMP, which have proven effective in improving surgical outcomes. By fostering a healthcare environment that supports preventive care and advanced treatment options, the incidence of pseudarthrosis can be significantly reduced, enhancing patient quality of life and reducing the financial burden on the healthcare system.

While smoking cessation and advanced therapies offer significant promise, some patients may still develop pseudarthrosis regardless, highlighting the need for ongoing research and refinement of therapeutic approaches. The economic burden of pseudarthrosis remains substantial, emphasizing the importance of continued investment in preventive measures and effective management strategies. Despite the high initial costs, advanced treatments like BMP therapy can lead to long-term savings by reducing the need for costly reoperations. Ultimately, implementing comprehensive strategies that address both surgical and patient-related factors is essential to improve spinal fusion outcomes and mitigate the financial impact of pseudarthrosis. By integrating these approaches into clinical practice and policy-making, the healthcare system can achieve better patient outcomes and more sustainable economic benefits.

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