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World Journal of Orthopedics (*World J Orthop*, *WJO*, online ISSN 2218-5836, DOI: 10.5312) is a monthly peer-reviewed, online, open-access, journal supported by an editorial board consisting of 261 experts in orthopedics from 30 countries.

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TOPIC HIGHLIGHT

Shigeru Kobayashi, MD, PhD, *Series Editor*

Pulmonary complications after spine surgery

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Abstract

Spine surgery is one of the fastest growing branches of orthopedic surgery. Patients often present with a relatively high acuity and, depending on surgical approach, morbidity and mortality can be comparatively high. Among the most prevalent and most frequently fatality-bound perioperative complications are those affecting the pulmonary system; evidence of clinical or subclinical lung injury triggered by spine surgical procedures is emerging. Increasing burden of comorbidity among the patient population further increases the likelihood of adverse outcome. This review is intended to give an overview over some of the most important causes of pulmonary complications after spine surgery, their pathophysiology and possible ways to reduce harm associated with those conditions. We discuss factors surrounding surgical trauma, timing of surgery, bone marrow and debris embolization, transfusion associated lung injury, and ventilator associated lung injury.

Key words: Spine surgery; Complications; Pulmonary; Pulmonary embolism; Transfusion-associated lung injury; Ventilator-associated lung injury

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INTRODUCTION

The number of spine surgical procedures has been increasing dramatically over the last decade[1]. This trend has made this population a prominent group among hospitalized patients, especially since they are accompanied by relatively high medical acuity. Depending on surgical approach, perioperative complications may occur in over 20% of patients, with those requiring thoracic approaches suffering the highest morbidity[2]. Amongst complications, those affecting the pulmonary system are of special concern as they have been linked to high rates of mortality[2]. Indeed, almost half (43.7%) of patients dying after lumbar spine fusion do so with a diagnosis of pulmonary compromise. Adult respiratory distress syndrome (ARDS) occurs in up to 3% of patients and will increase the risk of in-hospital death by more then 6-fold[2]. This is especially of concern as pulmonary complications have been on the rise amongst an increasingly comorbidity ridden spine surgical population[1]. Further, studies suggest that a large number of spine surgical patients show evidence of lung injury, albeit often subclinical[3,4].

A better understanding of the associated pathophysiology could allow for improvements in outcome. While the mechanisms leading to the development of pulmonary complications are likely multifactorial, they do include direct mechanical trauma due to parenchymal contusion, embolization of marrow material into the lung, ventilator associated lung injury and the entity of transfusion related lung injury[3-8]. In this article, we will review potential mechanisms contributing to lung injury and point to possible ways to reduce it.

EPIDEMIOLOGY

The most important indications for spine surgery include degenerative disc disease and associated pain and disability, followed by stenosis, scoliosis and spondylolisthesis. Other indications include trauma and neoplastic disease. In the time period between 1988 and 2001, the number of spine fusions in the United States increased from some 24 000 to more than 120 000 procedures per year[9,10]; degenerative disc disease as a primary diagnosis was present in almost two thirds of cases (65.3%) by 2001[11]. Taking a closer look at the available data, the rate of surgery increased by approximately 100% during the 1980s and more than 220% during the 1990s. After 1996, when intervertebral fusion cages received approval by the food and drug administration, an exponential increase in case burden was seen. In 2001, depending on age group, as many as 60 to 90 per 100 000 patients underwent cervical, thoracic or lumbar spine fusion[11]. The most dramatic rise was evident in the group of patients aged 60 or older in all procedures except cervical spinal fusion, which peaked in the group aged 40 to 59 years[9]. Rates of spinal fusion surgery have been maintaining their steady increase during the first decade of the 21st century, surpassing 110 per 100 000 patients in 2003, while at the same time exhibiting considerable regional variability[12]. In contrast, the volume of discectomy and laminectomy procedures stagnated, but the fraction of outpatient procedures among these increased[13]. Given the increasing age of patients and preferred treatment patterns for degenerative disease[14], the upwards trend of spinal fusion procedures incidence is likely to perpetuate in the next years[1].

The aforementioned developments, which essentially represent a shift towards a rising number of procedures with increased invasiveness being performed among an older, comorbidity ridden population, necessitate a close analysis of outcomes and associated risk factors. Procedure-related immediate complications occur in up to 20% and in-hospital mortality rates of 0.2%-0.5% have been recorded[1]. These numbers are contingent upon a number of independent risk factors, including male gender, advanced age, surgical approach (anterior *vs* posterior *vs* anterior/posterior approach, the latter being associated with the highest odds for morbidity and mortality), and preexisting comorbidities[15]. Most significantly associated with a higher mortality are known diagnoses of congestive heart failure, liver disease, coagulopathy, neurologic disorders, renal disease, electrolyte imbalances and pulmonary circulatory disease. Aside from device-related adverse events, respiratory complications rank among the most common and most serious procedure-related complications after spine surgery. They occur in up to 3.82% of subjects, especially after anterior and anterior/posterior surgical approaches and are associated with high mortality. Patients are fundamentally more prone to suffer in-hospital death after having developed ARDS [odds ratio (OR) 5.85], pulmonary embolism (OR 8.17) or other lung-associated conditions (OR 1.45)[2]. These ORs represent the relative adjusted risk for in-hospital mortality in patients who suffered from the complication, compared to those who did not (1 = reference).

MECHANICAL TRAUMA

Intuitively, surgical extent and invasiveness are closely correlated with the risk for adverse events. It has been shown that more extensive procedures, especially those necessitating invasion of the thoracic cavity, are burdened with higher rates and risk of complications[2]. Indeed, approximately 3% of patients will develop ARDS after anterior/posterior spine surgery compared to approximately 1% after a posterior or 1.6% after an anterior approach only[2].

Possible explanations include contusion and direct mechanical trauma due to the invasion of the thoracic cavity and displacement of the lung to gain access to the spine. However, it remains unknown if simple displacement of the lung offers any advantage to lung isolation and collapse during surgery as both may be burdened with disadvantages. In the first case, direct mechanical trauma may lead to tissue damage and its sequelae, while in the latter the phenomenon of re-expansion pulmonary edema may become a source of concern[16]. In addition, the effect on the contralateral lung has to be kept in mind in the context of pathologic events summarized under the term "down lung syndrome"[17].

EMBOLIZATION OF MARROW AND BONE DEBRIS

Similarly to events described during joint arthroplasty procedures, evidence is emerging that the intravasation of marrow and bone debris during the instrumentation process may contribute to perioperative lung injury[18]. Here, the embolization of material into the pulmonary vasculature has been associated both with parenchymal damage and increases in pulmonary vascular resistance in a dose dependent manner[19,20]. In the spine surgical setting, Urban *et al*[6] was able to demonstrate an adverse pulmonary effect of perioperative events in the form of an increase in pulmonary vascular resistance in 15% (8/55) of patients, usually during or after posterior instrumentation. In a follow-up study, Urban *et al*[5] analyzed bronchoalveolar specimens and linked the presence of lipid-laden macrophages to possible embolization of fat and debris entering the bloodstream during the surgical procedure. This mechanism of lung injury is supported by echocardiographic studies, in which 80% of spine surgery patients experienced moderate to severe embolic events during instrumentation of the spine[7]. Markers of lung catabolism showed a significant increase in the postoperative period compared to baseline[4].

While the load of embolic material may be a determinant of the extent of lung injury, the patient's ability to compensate for the pathophysiologic changes is almost certainly a major factor in the ability of patients to compensate for the insult. In this context, we previously reported a dramatically increased risk for mortality in those patients with pre-existing pulmonary hypertension [OR 8.37 (95%CI 5.95-11.78)][2].

It has been speculated that an increase in pulmonary vascular resistance may lead to increased right ventricular and atrial pressures and thus decreased venous return. This in turn may promote arrhythmias, secondary to right heart dilatation and the formation of venous thrombosis and embolic events[21].

TRALI AND MASSIVE RESUSCITATION

Significant blood loss is an important issue in major spine surgery and frequently necessitates replacement of blood products. Although the risk of infectious disease transmission through transfusion has declined substantially, other complications must be kept in mind. These complications include immediate and delayed hemolysis, febrile and allergic reactions, systemic inflammatory response syndrome, disruptions of coagulation, electrolyte and acid-base household as well as other immune-system mediated conditions like graft-*vs*-host disease and, most significantly, transfusion-associated acute lung injury (TRALI). TRALI has emerged as the leading cause for transfusion-associated mortality[22]; it is defined as new acute lung injury occurring during or within 6 h after a transfusion. All available blood products have been reported to cause TRALI; those with high plasma content seem to be involved more frequently. While initial reports stated a per component incidence between as high as 1:432 for whole blood platelets and 1:557 000 for red blood cells[22], recent efforts to screen for and exclude high risk cases both on the sides of donor and recipient seemed to succeed in reducing the incidence of TRALI. A reduction in TRALI incidence rate for plasma transfusion from 1:4000 in 2006 to 1:12 000 in 2009 has been reported[23]. Clinical and diagnostic features of TRALI include dyspnea, hypoxia, fever, tachycardia, bilateral pulmonary edema without evidence of congestive heart failure or volume overload and bilateral fluffy infiltrates on chest radiograph[24]. In contrast to the non-immunologic transfusion-associated circulatory overload-an important and very similarly presenting differential diagnosis-TRALI is probably caused by antibodies adhering to neutrophils in the recipients' pulmonary epithelium. These activated neutrophils release oxidases and other reactive substances provoking damage to the capillary membrane and, subsequently, capillary leak and pulmonary edema[25]. For about 15% of cases in which no antibodies could be found, other sources of capillary damage have been suggested, including involvement of lymphocytes and monocytes, cytokines, lipid priming molecules and endotoxins. Treatment of TRALI is primarily supportive; ventilatory support and supplemental oxygen is required in most cases, while a beneficial influence of steroid administration is not proven. Diuresis is not recommended[26]. Unlike in ARDS caused by other pathologies, patients usually recover quickly after TRALI, most within 96 h of the transfusion, and mortality is relatively low, ranging between 5% and 10%[24].

Massive transfusion has been defined as administration of more than 10 units of packed red blood cells in a 24 h period[27]. One of the most important problems arising with this entity is the alteration of intravascular blood homeostasis, resulting in coagulopathy, electrolyte imbalance, acidosis and hypothermia, which can all be difficult to counteract and give rise to a number of associated conditions on their part. Particularly imbalances of coagulation as well as pre-existing coagulopathy have been associated with a high predictive risk for mortality after spine fusion [OR 5.46 (95%CI 4.34-6.86)][2]. Further, as the risk for development of complications is proportionate to the number of units transfused, a cautious transfusion regimen can be advantageous wherever possible[28]. In terms of survival and improved surgical outcome, a liberal transfusion regimen has recently not proven beneficial even in high risk patients after hip surgery, another form of orthopedic surgery where high blood loss is frequently an issue[29].

VENTILATOR ASSOCIATED LUNG INJURY

Mechanical ventilation is necessary during the perioperative period in order to provide sufficient respiration and oxygenation to the anesthetized patient. Historically, tidal volumes as high as 15 mL/kg ideal body weight (IBW) have been utilized, generating mechanical stress on the lung parenchyma. These high tidal volumes were believed to ensure bronchiolar patency and avoid atelectasis[30]. Only recently studies suggested that the usage of tidal volumes in a physiologic range (6 mL/kg IBW) could prevent pulmonary adverse outcomes including acute lung injury and ARDS[31]. In principle, mechanical ventilation is thought to generate physical damage through overdistension (volutrauma) and excessive transpulmonary pressure (barotrauma) as well as pulmonary inflammatory response and disruption of structural element metabolism[32]. During intrathoracic procedures this adds up to surgically induced trauma and the extent of pulmonary injury is likely contingent upon the accumulated total tissue interference. A number of recent studies suggest that a protective ventilation strategy can contribute to beneficial outcome of spine surgery[8]. Efforts to quantify the trauma by measuring markers of inflammation and elastin catabolism, including plasma cytokines, myeloperoxidase and elastin in bronchoalveolar lavage fluid and desmosin in the urine, showed conflicting results. However, a substantial rise in inflammatory markers after surgery could be noted irrespective of which ventilation approach (i.e., low or traditional tidal volumes) was chosen[33].

One-lung ventilation (OLV), achieved using bronchial blockers or double-lumen endobronchial tubes, improves intrathoracic visualization for the surgeon while reducing the risk of trauma inflicted through mechanical interference with the lung. Although the cardiac output shunt fraction increases drastically as soon as one lung is excluded from ventilation and gas exchange, satisfactory oxygen saturation levels above 90% can be maintained in up to 80%-90% of cases even with low to medium sized tidal volumes[34]. Other complications of OLV include tracheal or bronchial injury during placement of the double lumen tube, re-expansion pulmonary edema[16] and adverse effect on the contralateral lung through ventilation-, surgery- or position-associated additive stress[17].

TIMING OF SURGERY

It has been well established that more extensive surgery harbors increased risk of pulmonary complications, with combined anterior and posterior procedures being associated with highest risk. To date it remains controversial if performing both portions of surgery in one or in separate sessions can modify this risk. Studying this question poses extensive limitations as sufficient sample sizes are difficult to achieve in order to provide sufficient statistical power.

In a study utilizing nationally representative data from 113 991 cases, we found increased rates of pulmonary complications in those undergoing staged procedures performed during the same hospitalization (5.0% *vs* 3.3%, $P < 0.0001$). While controlling for surgical indication, patient demographics including comorbidity burden, many clinical factors could not be accounted for in this analysis, thus limiting the interpretation of data. Although we cannot exclude that staged cases may have been more invasive, the findings suggest that the performance of a second surgery during the time of increased perioperative systemic inflammation may contribute to higher rates of complications. This is a finding also observed in staged bilateral total knee arthroplasties, which share similar pathophysiologic set ups[35].

POTENTIAL INTERVENTIONS TO DECREASE LUNG INJURIES

A myriad of factors that individually, but also cumulatively contribute to the development of pulmonary complications after spine surgery has been described. Therefore, a multimodal approach is required to effectively counteract these factors and thereby improve outcomes.

Avoiding ventilation associated lung injury

The combined insult of surgical manipulation and mechanical ventilation to the lung parenchyma can be mitigated by trying to minimize the adverse impact of both. Thoracoscopic and microsurgical approaches can reduce the trauma associated with thoracotomy[36]. One-lung ventilation reduces the potential harm through mechanical interaction with lung tissue while at the same time optimizing visualization and shortening intervention time. However, it is not clear if the benefits outweigh the side effects of these methods, including re-expansion pulmonary edema and down lung syndrome. Ventilation with a lower tidal volume than traditionally used and high positive endexspiratory pressure has proven effective in intensive care patients, especially those suffering from acute ARDS[37]. For a relatively short duration of mechanical ventilation in patients with healthy lungs, which is usually the case during surgery, the significance of this approach is not yet proven.

Certainly, protective ventilation seems to be of equal importance in one lung ventilation. Low tidal volumes (4-6 mL/kg IBW) have shown to reduce the risk of lung injury after thoracotomy[38] as well as permissive hypercapnia, which is thought to improve oxygenation by increasing hypoxic pulmonary vasoconstriction and, consequently, reducing shunt volume[39].

Decreasing blood loss

There are several approaches to decrease bleeding and reduce the requirement for blood component substitution. Pharmacological agents to address this matter include the antifibrinolytics tranexamic acid and epsilon-aminocaproic acid, which have proven effective in reducing blood loss during spinal surgery with no substantial side effects[40]. Further, studies evaluating the use of recombinant factor Ⅶa show promising initial results, although there are concerns about its safety in terms of thrombotic complications[41].

The utilization of neuraxial blocks has also demonstrated favorable reductions in intra- and postoperative bleeding[42]; this effect might originate in hypotension caused by the block which can be undesirable in major spine surgery, as well as the possible impairment of postoperative neurological assessment. However, intrathecal opioids, which may reduce the sympathetic response to pain, may have fewer disadvantages; a number of studies have shown their safety and efficacy in pediatric spinal fusion surgery[43-45].

Above all, achievement of hemostasis in a timely manner is probably one of the most important factors contributing to improved outcome. Among other interventions, this can be facilitated by local skin infiltration with epinephrine, usage of topical hemostatic agents, favoring minimally invasive techniques, and ensuring normal body temperature[46].

Blood centers began to implement protocols to reduce the incidence of TRALI. Multiparous females and subjects with a history of receiving blood transfusions are considered the highest risk donors, because their likelihood of having developed anti-human-leukocyte antibodies is particularly high. In some countries including the United States, plasma is now primarily being produced from male blood donors. Another approach is the usage of pooled solvent detergent plasma, which has reportedly never been implicated in a case of TRALI. For platelets, this strategy is not yet feasible. Due to the limited availability of apheresis donors, exclusion of all female donors would result in a substantial supply shortage[24].

Preventing pulmonary embolism

The thromboembolism risk of spine surgery patients not receiving chemical prophylaxis has been reviewed elsewhere[47], and was found to be approximately 5.3% in deformity cases, and 2.3% in those operated on for degenerative disc disease. The risk of thromboembolism in elective spine surgery is generally believed to be very low in otherwise healthy patients. Although rarely with complications (such as postoperative bleeding, symptomatic epidural hematoma or potential neurological deficits), considering the potential adverse events associated to anticoagulation, chemical prophylaxis is not routinely recommended in addition to mechanical prophylaxis in elective spinal surgery[47,48]. Evidence-based guidelines for antithrombotic therapies in spine surgery have been established by the North American Spine Society (NASS)[48] and are available *via* the NASS website[49].

CONCLUSION

Spine pathologies impart a large socioeconomic impact on our health care system. Given an increasingly ageing population with comorbid conditions, the number of spine surgery procedures must be expected to rise. Pulmonary compromise is seen in almost half of patients who die following spine surgery. Thus, pulmonary complications and associated risk factors deserve special consideration in preoperative planning and patient selection. Strategies to proactively improve patient outcome include careful preoperative identification of patients with pulmonary and/or systemic comorbidity, stratification of patients by risk and, subsequently, selection of appropriate surgical and anesthesiologic management. A multimodal approach is required to effectively counteract factors that contribute to the development of pulmonary complications after spine surgery.

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BRIEF ARTICLE

Intraprosthetic fixation techniques in the treatment of periprosthetic fractures: A biomechanical study

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Abstract

AIM: To develop new fixation techniques for the treatment of periprosthetic fractures using intraprosthetic screw fixation with inserted threaded liners.

METHODS: A Vancouver B1 periprosthetic fracture was simulated in femur prosthesis constructs using saw-bones and cemented regular straight hip stems. Fixation was then performed with either unicortical locked-screw plating using the less invasive stabilization system-plate or with intraprosthetic screw fixation using inserted liners. Two experimental groups were formed using either prostheses made of titanium alloy or prostheses made of cobalt chrome alloy. Fixation stability was compared in an axial load-to-failure model. Drilling was performed using a specially invented prosthesis drill with constantly applied internal cooling.

RESULTS: The intraprosthetic fixation model with titanium prostheses was superior to the unicortical locked-screw fixation in all tested devices. The intraprosthetic fixation model required 10 456 N ± 1892 N for failure and the unicortical locked-screw plating required 7649 N ± 653 N ($P < 0.05$). There was no significant difference between the second experimental group and the control group.

CONCLUSION: Intraprosthetic screw anchorage with special threaded liners enhances the primary stability in treating periprosthetic fractures by internal fixation.

Key words: Periprosthetic fracture; Less invasive stabilization system; Plate fixation; Intraprosthetic screw fixation; Material science; Biomechanical testing; Axial load-to-failure

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INTRODUCTION

The number of implanted hip prosthesis is still increasing all over the world[1]. This increase and the growth in life expectancy will higher the incidence of periprosthetic fractures[2,3]. Today, the risk of a periprosthetic fracture is about 0.3%-2.0% in the first years after implantation[3-7].

Operative treatment is the first choice and non-operative treatment is reserved only for special situations. The best method of operative treatment is still controversial and depends on different factors[8]. The Vancouver-classification is very useful in choosing the right treatment of these fractures. No doubt, fractures with unstable stems (B2)[9-12] should be treated by revision arthroplasty[13-15]. Fractures with a stable stem can be treated by osteosynthesis. However, the best way of stabilization is still controversial. Plate fixation[16-21], cerclages[22-24], and even external fixation[25,26] are described in the literature. Several studies have emphasized the advantage of locking screws. But the screw anchorage in the proximal fragment might be limited due to a mismatch between a big stem and thin cortical shell.

The strongest part in the proximal part is the prosthesis itself. Thus, the idea of an intraprosthetic screw fixation arises to enhance stability in the proximal part. The presented biomechanical study compares the stability of intraprosthetic screw fixation using glued liners inserted in either hip prostheses made of titanium alloy or cobalt chrome prostheses and locked plating in a simulated fracture model (Vancouver B1). We hypothesized significant higher fixation strength to axial loading in the intraprosthetic fixation groups.

MATERIALS AND METHODS

Drill-machine

The developing process of the intraprosthetic drill-machine has already been part of another publication[27]. High-performance cutting (HPC)-drills were used in this study that are strong and stable enough to provide optimal intraprosthetic drilling and connectivity to commonly used manual drilling machines in trauma surgery. Temperature control to tissue preserving levels during the drilling process was performed with the use of a custom made constantly applied internal cooling solution with a special transportation channel for removing the produced chips. The used liners were thread cut before inserting into prosthesis. To achieve optimal screw fitting thread cutting was performed using a regular thread cutter. They were then glued into the borehole after drilling the prosthesis using regularly used fibrin glue.

Specimen preparation

A total of twelve synthetic femurs (Sawbone Composite medium third generation, Pacific Research Labs Vashon Island, Washington, United States) were used instead of donor bones because of their availability and their equal shape and mechanical characteristics. A conventional straight stem prosthesis (Ecofit, Fa. Implantcast, Buxtehude, Germany) was implanted in each femur using bone cement for implantation to provide equal primary stability of the stems among all femurs. Titanium stems were used in eight femurs; prostheses made from chrome-molybdenum were implanted in four femurs.

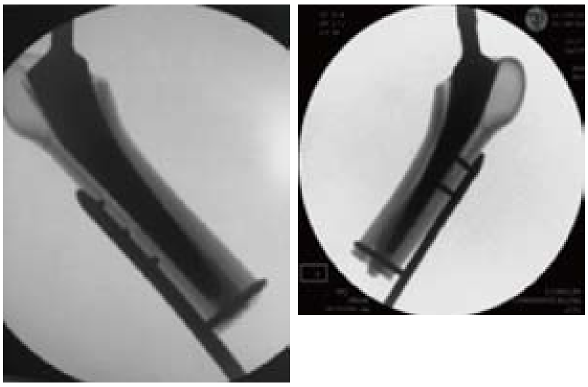

Figure 1 X-ray shots of unicortical and intraprosthetic screw anchorage. The figure shows the different fixation techniques evaluated in this study. Commonly used unicortical screw fixation with only a short anchoring distance and experimental intraprosthetic fixation with superior primary fixation stability.

The femurs were osteotomized 15 mm below the tip of the stem to create a Vancouver type C periprosthetic fracture. The screw fixation in the proximal part of the femur was our point of interest. The distal femur was abandoned and not involved in the study. We chose a commercial titanium locking plate (9-hole Less Invasive Stabilization System, Synthes, West Chester, United States) for the fixation. This locking plate is recommended for periprosthetic fractures of the femur and was tested in different studies[17,28,29]. Specially designed periprosthetic screws (ø 4 and 5 mm Periprosthetic Locking Screws, Synthes, PA, United States) are available to increase the number of threads within the unicortical fixation.

The company provided us with screw blanks, which had the threaded locking head but a non-manufactured shaft. We customised threads that fitted to the threads of the liners within the prosthesis.

In the control group the locking plate was fixed with three unicortical locking screws implanted at the level of the prosthesis made from titanium alloy and one solid bicortical locking screw below the tip of the cemented stem (Figure 1).

In the experimental group with implanted titanium prostheses the locking plate was fixed with the same bicortical screw configuration beneath the tip of the prosthesis. At the level of the prosthesis only two intraprosthetic screws were implanted instead of the three unicortical screws (Figure 1). After drilling two holes at the level of the prosthesis (insertion depth 10 mm), the liners were inserted using fibrin glue. The internal thread was made for the reception of 4 mm locking screws. Due to the insertion of the screw the liners spread and clamped the bore channel. In the third group with cobalt chrome prostheses the fixation technique was similar to the one described in the first experimental group. The screws were inserted with the commercial torque wrench.

The distal plate end was fixed in a specially designed cup with locking screws to provide maximum stability during testing (Figure 2). An insertion angle of 6 degrees

Figure 2 Illustration of testing model for axial load. The regular straight stem prosthesis was implanted into sawbones using bone cement. A Vancouver B1 fracture was then simulated and the construct was mounted on a testing device using a custom made angular stable fixation. Constantly increasing axial loading was then performed.

valgus was chosen following the mechanical axis of the femur of the leg.

Mechanical testing

Tests were performed with the prepared specimens mounted in a universal testing machine using a custom made locking screw device for the less invasive stabilization system (LISS)-plate fixation (Zwick Z250, Zwick, Ulm, Germany) (Figure 2). A standard commercially available metal head (32 mm) was placed at the top of the implanted prosthesis. A constantly increasing load was applied to the metal head in the anatomical axis of the femur with a starting force of 0 nm. The applied force was continuously measured and recorded. Reversible (elastic) and irreversible (plastic) deformation was expected. Elastic during the continuously load increase and plastic at the primary endpoint with either plastic deformity of the LISS plate or an irreversible loss of integrity of the whole locking plate fixation with avulsion of the locking screws.

Statistical analysis

The loads to failure values were evaluated using a student's *t*-test. The following null-hypothesis was set: Equality of all tested fixation techniques regarding maximum axial load forces and failure of the locking screws. A value of $P < 0.05$ was chosen.

RESULT

The intraprosthetic group with straight stems made of titanium and inserted threaded liners failed at an average of 10 456 N ± 1892 N, the group with cobalt chrome stems and liners failed at an average of 9781 N ± 2323 N. The control group failed at an average of 7649 N ± 653 N. There was a significant difference found between the control group and the experimental group with liners and hip stems made of titanium alloy ($P < 0.05$). There was no significant difference between the control group and the other experimental group with the cobalt chrome stems ($P > 0.05$).

All drillings were successfully done without any problems in tapping, insertion or locking. No hardware failure occurred during implantation. In all tested devices in the control group a loss of fixation integrity at the level of the implanted prosthesis was observed. A total blow out of all unicortical screws was seen in 3 of 4 tested devices in this group.

There was no such hardware failure in the first experimental group; increase of axial loading lead to a bowing in the plate device in these cases rather than to a blow out of the liner-screw construct at the level of the prostheses. Differently, in the second experimental group with the cobalt chrome prostheses a loss of integrity at implant level was observed in two constructs at maximum axial loading.

DISCUSSION

This study was performed to compare different fixation techniques for the treatment of Vancouver type B1 periprosthetic fractures of the proximal femur. The most important finding of our study was that intraprosthetic screw fixation provided significantly higher failure loads compared to unicortical locked-screw plating in the titanium alloy fixation group. There were no significant differences between the control group and the second experimental group using cobalt chrome stems. Reasons for the different axial loads between the two experimental groups are plausibly caused by the differences between the materials used. Both, drilling the channel and inserting the liner with its clip function do work better in hip stems made of titanium alloy. Those implants are easier to process, drilling is easier to control and to perform, and caused by the lower level of stiffness and rigidity gluing and clipping the liner is more stable.

Intraprosthetic fixation leads to a significant increase in primary stability without weakening the implant-cement-femur-model that could lead to an early weight-bearing patient mobilization. Furthermore, we observed high standard deviations in both experimental groups compared to the control group. This seems to be caused by different positioning of the intraprosthetic screw. Although drilled with the use of fluoroscopy, there were still different results in screw fitting distance. This could explain the high standard deviation. Additionally, it shows the superiority of the intraprosthetic construct with reaching higher loading forces even with eccentric drilling and a reduced intraprosthetic screw fitting distance.

Limitations of the presented experimental biomechanical testing are the small number of cases in each group. Because of the study design and the comparability between both groups the number of cases seems to be large enough to produce useful results. The use of identical synthetic composites secures a high level of comparability between both groups. Additionally, compared to the thinner cortical strength of older osteoporotic bone the thicker cortical strength with the composite femurs is likely to be an advantage for the control group. Furthermore, the use of cement favors the control group by increasing the anchoring screws. With these tests the focus was only on the proximal fixation as weak point of locking screw fixation.

This new idea of intraprosthetic fixation in the treatment of periprosthetic fractures has not been published before. Presently, a variety of different operative treatments exist depending on the fracture location and stability of the stem[30]. Comparable extension forces have not been published before.

Dennis *et al*[30] presented a biomechanical review of five different fixation techniques. In axial loading tests plate constructs with proximal unicortical screws and distal bicortical screws were more stable than constructs with cables or plates and cables. In axial compression displacement in the most stable groups started at a maximum compression load of 4977 N. Other authors described satisfactory results with the use of simple conventional plating[2,31], angular stable internal fixation[17] or indirect reduction without grafting[19,20].

Especially with thinner, osteoporotic bone stock, intraprosthetic fixation could lead to an increase in primary stability. This technique might be even more superior in very osteoporotic femurs with a very small cortical shell. During testing even eccentric drilled screws in the prosthetic stem achieved significantly higher primary stability than the control group. A weakening of the implanted prosthesis actually appears implausible but not impossible. A main problem with intraprosthetic drilling might be the control of the heat development during drilling procedure and the transportation of the metal chips. With the use of custom-made continuously internally cooled HPC-drills with a special transportation channel, these problems might have been resolved.

The actual presented study has to been seen as a preliminary load to failure evaluation. Further studies are necessary to prove the mechanical integrity of the prosthesis and the bony anchorage of the prosthesis as well as the avoided temperature increase and the evacuation of the metal debris. Additionally, further testing should also focus on securing the optimal screw position for intraprosthetic anchorage to achieve the highest level of anchorage strength without weakening the prosthesis. Furthermore, one of the next steps will be the testing of the dynamic stability of the intraprosthetic screw fixation technique.

Intraprosthetic screw anchorage in titanium prostheses with special threaded liners enhances the primary stability in treating periprosthetic fractures by internal fixation.

COMMENTS

Background

The number of implanted hip prostheses is still increasing and so is the number of proximal femur fractures after total hip replacement. Fractures with an unstable hip stem are generally treated with revision arthroplasty and the use of a longer hip stem. For the treatment of fractures with a stable stem various techniques have been described, e.g., unicortical plate fixation, cerclages, struts, but none of them seems to be superior to the others. To improve the primary stability different intraprosthetic fixation techniques were tested for axial loading forces in this presented study.

Research frontiers

Intraprostheitc screw fixation represents a new idea and technique to improve the primary stability in the treatment of periprosthetic fractures. Intraprosthetic fixation was achieved with the use of thread cut liners that were inserted into the drilling hole. The liners were then used like dowels.

Innovations and breakthroughs

New techniques of intraprosthetic screw fixation were described. Compared to the commonly used unicortical plate fixation the axial loading forces achieved were significantly higher in the experimental group using hip stems made of titanium alloy. There was no significant difference between the second experimental group using cobalt chrome prostheses. All drillings were done successfully without problems in drilling, inserting or locking. Although an experimental biomechanical study, the results could lead to a future change in the treatment of periprosthetic fractures to a significant increase in primary stability.

Applications

Intraprosthetic screw anchorage in titanium prostheses with special threaded liners enhances the primary stability in treating periprosthetic fractures by internal fixation. This could lead to a change in the treatment algorithm of periprosthetic fractures to allow early weight bearing and reduce the in-hospital morbidity with older patients.

Terminology

Periprosthetic fracture describes a fracture of an example the proximal femur after the patient underwent total hip replacement. The treatment is depending on the stability of the implanted hip stem. Intraprosthetic screw anchorage describes a new technique of screw fixation were the bore hole is drilled into the prosthesis using a specially developed drill. Plate fixation and cerclages are different techniques in fracture treatment.

Peer review

The authors present an interesting report of a novel fixation technique for periprosthetic fractures of the femur. With static loading, they show that the new technique is more stable than conventional plating in the titanium constructs. Because of its novelty, it might be interesting to readers.

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January 23-25, 2012
8th Middle East Orthopaedics Conference "Future Challenges and Directions in Orthopedic Surgery"
Dubai, United Arab Emirates

February 7-11, 2012
American Academy of Orthopaedic Surgeons
San Diego, CA, United States

February 14-15, 2012
7th National Conference: Orthopaedics and Sports Medicine 2012 London, United Kingdom

February 16-19, 2012
Orthopaedic MRI and Small Parts
Scottsdale, AZ, United States

March 4-8, 2012
The 30th Annual Emergencies in Medicine Conference
Utah, UT, United States

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ICJR 2nd Annual Advances in Orthopaedic Trauma and Arthroplasty Course
Florida, FL, United States

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Orthopaedics and Sports Medicine for Primary Care Practitioners
Honolulu, HI, United States

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Association of Bone and Joint Surgeons
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6 21st century heart solution may have a sting in the tail. *BMJ* 2002; **325**: 184 [PMID: 12142303 DOI:10.1136/bmj.325.7357.184]

Volume with supplement

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9 Outreach: Bringing HIV-positive individuals into care. *HRSA Careaction* 2002; 1-6 [PMID: 12154804]

Books

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10 **Sherlock S**, Dooley J. Diseases of the liver and billiary system. 9th ed. Oxford: Blackwell Sci Pub, 1993: 258-296

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Conference paper

14 **Christensen S**, Oppacher F. An analysis of Koza's computational effort statistic for genetic programming. In: Foster JA, Lutton E, Miller J, Ryan C, Tettamanzi AG, editors. Genetic programming. EuroGP 2002: Proceedings of the 5th European Conference on Genetic Programming; 2002 Apr 3-5; Kinsdale, Ireland. Berlin: Springer, 2002: 182-191

Electronic journal (list all authors)

15 Morse SS. Factors in the emergence of infectious diseases. Emerg Infect Dis serial online, 1995-01-03, cited 1996-06-05; 1(1): 24 screens. Available from: URL: http://www.cdc.gov/ncidod/eid/index.htm

Patent (list all authors)

16 **Pagedas AC**, inventor; Ancel Surgical R&D Inc., assignee. Flexible endoscopic grasping and cutting device and positioning tool assembly. United States patent US 20020103498. 2002 Aug 1

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