European Journal of Trauma and Emergency Surgery **Original Article**

An *in Vivo* Experimental Comparison of Stainless Steel and Titanium Schanz Screws for External Fixation

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Abstract

Objective: To compare the clinical benefits of stainless steel (SS) to titanium (Ti) on reducing pin track irritation/infection and pin loosening during external fracture fixation.

Methods: A tibial gap osteotomy was created in 17 sheep and stabilized with four Schanz screws of either SS or Ti and an external fixation frame. Over the 12 week observation period, pin loosening was assessed by grading the radiolucency around the pins and measuring the extraction torque on pin removal at sacrifice. Irritation/infection was assessed with weekly clinical pin track grading. A histological analysis of the tissue adjacent to the pin site was made to assess biocompatibility.

Results: A statistically non-significant trend for less bone resorption around Ti pins was found during the early observation period. However, at sacrifice, there was no difference between the two materials. Also, there was no difference in the extraction torque, and there was similar remodeling and apposition of the bone around the pins. A statistically non-significant trend for more infection about SS pins at sacrifice was found. Histology showed a slightly higher prevalence of reactionary cells in SS samples, but was otherwise not much different than around Ti pins.

Conclusions: There is no clinically relevant substantial advantage in using either SS or Ti pins on reducing pin loosening or pin track irritation/infection.

Key Words
Stainless steel · Titanium · External fixation · Pin loosening · Pin track infection

Eur J Trauma Emerg Surg 2007;33:59–68
DOI 10.1007/s00068-007-6053-5

Introduction

External fixation has been used to stabilize fractures since the 19th century [1]. This minimally invasive technique has clinical benefits over other fixation techniques, such as internal plating and nailing, as there is less additional damage to the blood vessels and soft tissues at the fracture and interlocking sites [2]. Hence, external fixation is still used as a technique to treat open fractures with extensive soft tissue damage [3], and as a secondary treatment for post-operatively infected fractures and pseudarthroses [1]. Also, the cost benefits of implementing external fixation techniques have resulted in this treatment being employed as a primary treatment of fractures in less developed countries.

Over the years, external fixation has been developed to optimize the fixation technique and improve fracture healing. However, premature pin loosening and pin track irritation/infection are still common postoperative complications associated with this technique [4–6]. Micro-motion of the pin with respect to the bone is a contributor to both pin loosening and pin track irritation/infection. Movement of the pin will disrupt bone remodeling activity at the bone/pin interface, inducing bone resorption with fibrous tissue formation between the bone and pin, leading to pin loosening [7]. Pin movement and subsequent increased bone resorption has also been shown to result in the

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Received: March 2, 2006; revision accepted: July 10, 2006;

presence of inflammatory granulation tissue [8, 9]. Furthermore, movement of the pin may disrupt the sealing effect of the soft tissues with the pin, giving external bacteria greater access to the internal environment and increasing the chance of infection.

It is generally believed that reducing micro-motion will reduce pin loosening and pin track irritation/infection. This can be achieved by increasing the stiffness of the external fixation system, such as by using stiffer frame constructs or decreasing the bone to frame distance. However, the most compliant part of the external fixator remains the pins. Another method to decrease bone/pin micro-motion would be to improve the osseointegration properties of the pin. The clinically accepted pin materials used for external fixation are titanium (Ti) and stainless steel (SS). These materials vary in their mechanical properties as well as their biocompatibility. Ti is the more flexible material, with an elastic modulus of 110 GPa, while SS is stiffer with an elastic modulus of 207 GPa [10]. However, Ti has better osseointegration properties. Studies on unloaded implants have classified Ti as a bioinert material that exhibits contact osteogenesis, while SS is a biotolerant material that results in distance osteogenesis [11]. Ti coated SS pins combine the positive features of both materials and have been shown to reduce pin loosening compared to uncoated SS pins in an *in vivo*, loaded, ovine model [12]. More recently, SS pins coated with hydroxyapatite (an osteoconductive osseointegration improving material have been shown to have a similar effect [13]. These finding suggests that the combination of higher stiffness and biocompatibility produces a superior implant that improves osseointegration by reducing micro-motion. However, Ti coated SS pins are not available for general clinical use and hydroxyapatite coated pins may be prohibitively expensive, e.g., developing countries and veterinary medicine.

Previous *in vivo* experiments that compare biocompatibility [14–16], osseointegration [15, 16] and infection rate [14] of Ti and SS have studied unloaded implants that are not exposed to the external environment and therefore cannot be compared to the external fixation situation. Larger stresses and micromotion at the bone/pin interface are characteristics of external fixation that are not considered in unloaded situations [9]. Also, the body's natural barrier to bacterial invasion, the skin, is impaired during external fixation [17], and therefore, previous studies on internal implants cannot be extrapolated to the external fixation situation. Hence, regardless of the previous investigations into SS and Ti implants, it is still unknown whether SS or Ti pins are more suited to the external fixation situation. This study aims to assess the clinical benefits of using SS or Ti Schanz screws on reducing pin loosening and pin track irritation/infection in a loaded, *in vivo*, ovine model.

Materials and Methods

Animals

Seventeen female, mature Swiss Alpine sheep (bodyweight (BWT) 58.8 ± 7 kg, age 4 ± 0.48 years-old, mean ± SD) were used in this study (approved by the Animal Experimentation Commission of the Veterinary Office of the Canton of Grison, Switzerland and followed the guidelines of the Swiss Federal Veterinary Office for the use and care of laboratory animals). Two weeks prior to and during the observation period, the sheep were housed in individual pens with protection slings that allowed full weight bearing while standing and walking within the pen, but did not allow recumbency to prevent adverse loading of the external fixator.

Sheep were randomly assigned to either the SS or Ti group at surgery. The SS group contained eight sheep and the Ti group contained nine sheep. Within each group, six animals were designated for quantitative analysis that involved pin removal post-mortem. The remaining animals from each group were designated for qualitative histology with pins.

Implants

Four modified Schanz screws (Seldrill®, Synthes) of the same material were implanted into each animal. The SS and Ti screws had identical geometry, with a diameter of 5.0 mm, a thread length of 40 mm and a total length of 125 mm. The screws were modified such that the self-drilling flutes were removed, as bone ingrowth into the flutes would make it difficult to assess osseointegration with the pin surface. The self-tapping tip was retained.

A custom built uni-lateral fixator was used [18]. This fixator was made from epoxy resin re-enforced with two carbon–fiber rods. This design provides high stiffness when locked with carbon–fiber rods. Yet, when the rods are removed, the fixator has a low bending stiffness to allow for *in-vivo*, non-destructive, bending stiffness measurement of the gap tissue to monitor progression of healing.

Surgical Technique

The operative procedure was performed under general anaesthesia according to a standardized protocol. After pre-medication, induction and intubation, the anaesthesia was maintained by isoflurane in a $N_2O:O_2$ mixture with a 2:1 ratio in a semi closed system. Preemptive analgesia was achieved by intrathecal application of 0.05 mg/kg BWT Xylazine and 4 mg/kg BWT Carprofen intravenously. No antibiotic drugs were administered postoperatively or during the observation period.

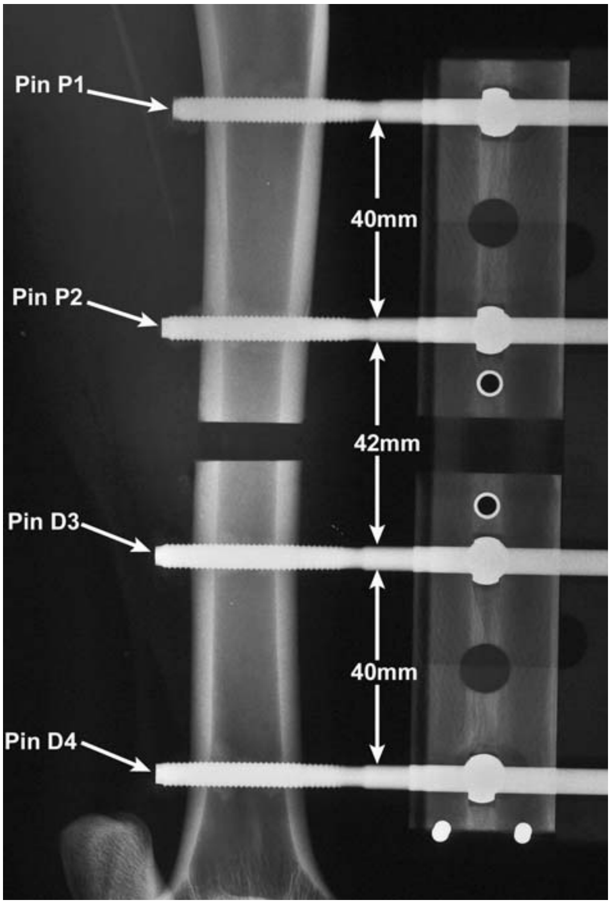

Figure 1. Post-surgery radiograph showing pin labeling and distance between the pins.

Table 1. Radiolucency grading scheme.

Grade	Observation
Grade 0	<0.5 mm or no radiolucency around the pin
Grade I	>0.5 mm, <2 mm radiolucency around the pin, partial cortical thickness, one or both cortices
Grade II	>2 mm radiolucency around the pin, partial cortical thickness one or both cortices
Grade III	Full cortical thickness radiolucency around the pin, one or both cortices
Grade IV	Sequester formation

The sheep were restrained in right lateral recumbency. After routine aseptic preparation of the right hind limb, a specially designed pin alignment guide was positioned on the antero-medial aspect of the tibial diaphysis. Small stab incisions were made in the skin, then a 3.2 mm diameter pilot hole was pre-drilled, followed by a 4.3 mm diameter hole to ensure radial preload of the 5.0 mm diameter screw in the bone. The insertion depth of the Schanz screw was calculated, such that the screw protruded 4–5 mm from the far cortex. The screws were inserted manually with a T-handle wrench to the calculated depth and labeled P1, P2, D3 and D4 from proximal to distal (Figure 1). P1 was inserted approximately 65 mm from the tibial plateau. After exposure of the medial aspect of the mid shaft tibial diaphysis, a transverse 6 mm gap osteotomy was performed with an oscillating saw halfway between P2 and D3. Previous research has shown that a 6 mm gap is not likely to bridge within a 12 week period [19, 20], hence the pin-bone interface would be loaded throughout the experiment.

After surgery, the sheep were closely monitored for 24 h. Post-operative analgesia was achieved with 4 mg/kg BWT Carprofen once daily for 2 days after surgery. The animals were monitored on a daily basis by trained animal caretakers and further post-operative analgesics were administered when necessary for up to 4 days post-operatively. Weekly clinical pin care included irrigation and debridement if necessary. Fluorescent markers were administered subcutaneously at 6 weeks (Xylenol Orange: 90 mg/kg BWT) and 10 weeks (Calcein Green: 5 mg/kg BWT) for post-mortem fluorescent histological analysis [21]. Euthanasia was performed after a 12 week observation period by an overdose of pentobarbital.

Clinical Assessment

Standardized cranial-caudal radiographs (55 KV and 16 mAs) were taken immediately after surgery and thereafter biweekly throughout the observation period and assessed for the appearance of bone resorption around the pin. Each pin site on each radiograph was assessed by a single, non-blinded observer (AG) for altered radiographic density and was graded according to the scoring scheme described in Table 1.

Pin track irritation/infection was assessed weekly throughout the observation period by a single, non-blinded observer (AG). Clinical signs of irritation/infection were graded according to a modified Checketts and Otterburn grading scheme (Table 2) [22]. The nature of advanced infection for this model was determined by taking sterile swabs from the periosteal surface of pin sites with high infection grades at sacrifice. The microorganisms present in these swabs were identified.

Biomechanical Assessment

Weekly *in vivo* bending stiffness measurements were taken of the osteotomy gap to assess the progression of fracture healing. This was achieved by using a specially made device, the details of which have been previously reported [18]. This device applied a non-destructive bending moment over the osteotomy gap and fixator and measured the stiffness. As the stiffness of the fixator was constant and known, the stiffness of the osteotomy gap could be determined. The stiffness values of the osteotomy gap were then normalized to the intact bone. Normal healing was indicated by an increase in gap stiffness after 3–4 weeks. A slight delay showed an increase in stiffness after 5–6 weeks, while a moderate delay showed an increase in stiffness after 6–8 weeks. Interrupted healing was defined as a period of normal increase in gap stiffness followed by a decrease in gap stiffness.

Insertion and extraction torque of the pins were measured in the sheep designated for pin removal postmortem. Insertion torque was measured during surgery. After full insertion, the pins were backed out two full revolutions and reinserted to their original position with an instrumented wrench connected to a data acquisition device (Honeywell Minitrend V5, Dorset, UK, and ADWin-Gold V3.2, Jäger Messtechnik, Lorsch, Germany). On extraction, the same instruments were used. The initial peak extraction torque indicated the strength of osseous integration.

Table 2. Pin track infection grading scheme based on a modified Checketts and Otterburn classification [22].

Grade	Observation
Grade 0	No sign of infection
Grade I	Slight non pus discharge Redness around the pins, warmth Local treatment required (debridement and irrigation)
Grade II	Redness of the surrounding skin Tenderness of the soft tissue ±1 Discharge of pus Local antiseptic treatment required
Grade III	Like grade II Fails to resolve with local antiseptic treatment
Grade IV	Like grade III The radiograph shows radiolucency around the pin
Grade V	Like grade III Sequester formation visible on the radiograph

Histological Assessment

The histological assessment aimed to provide supporting information for the outcomes from the clinical and biomechanical assessments in this study. As definitive conclusions were not drawn from the histology, a qualitative assessment was made. This was performed in two parts. The first part involved specimens from the six sheep per pin type that had the pins removed at sacrifice. These specimens were pooled together and selected to give a histological description of the various radiolucency and irritation/infection grades. The second part involved the remaining animals in each group whose pins were left in place after sacrifice. These specimens were assessed for differences in the nature of the bone adjacent to the pin surfaces for the two materials.

After sacrifice, the right tibiae were fixed in 4% phosphate buffered formalin and dehydrated in ethanol. The segments were then embedded in polymethylmethacrylate. Transverse sections were cut through the pin holes. The specimens with empty pin sites were cut and ground to a thickness of 80–100 μm. The pin-filled specimens were cut and ground to a thickness 150–200 μm. Macroradiographs were taken from all specimens and the two sections with the widest pin-hole diameters were selected. One of these sections was surface stained with toluidine blue and eosin. The other section was reserved for fluorescent analysis.

The qualitative assessment involved comparing the specimens and assessing the parameter of interest on a scale of none, low, medium or high. The stained sections were analyzed under the light microscope. Evidence of bone remodeling was determined by qualitatively assessing the presence and abundance of osteoblasts and osteoclasts. Infection was demonstrated by the presence of inflammatory cells (giant cells, granulocytes and monocytes). Osseointegration was indicated by the bone apposition up to the implant and the nature of the bone adjacent to the implant for the pin-filled specimens. The fluorescent sections were analyzed to determine the bone remodeling history [21] and the macroradiographs were used to assess porosity around the pin sites and periosteal reactionary bone growth [23].

Statistical Analysis

The radiolucency and clinical grading results were statistically assessed for significant differences between groups at 6, 8 and 12 weeks. Friedman tests (Mathematica, Wolfram Research Europe LTD, Oxfordshire, UK) were used to determine the effect at all four pin sites combined at each time point. If

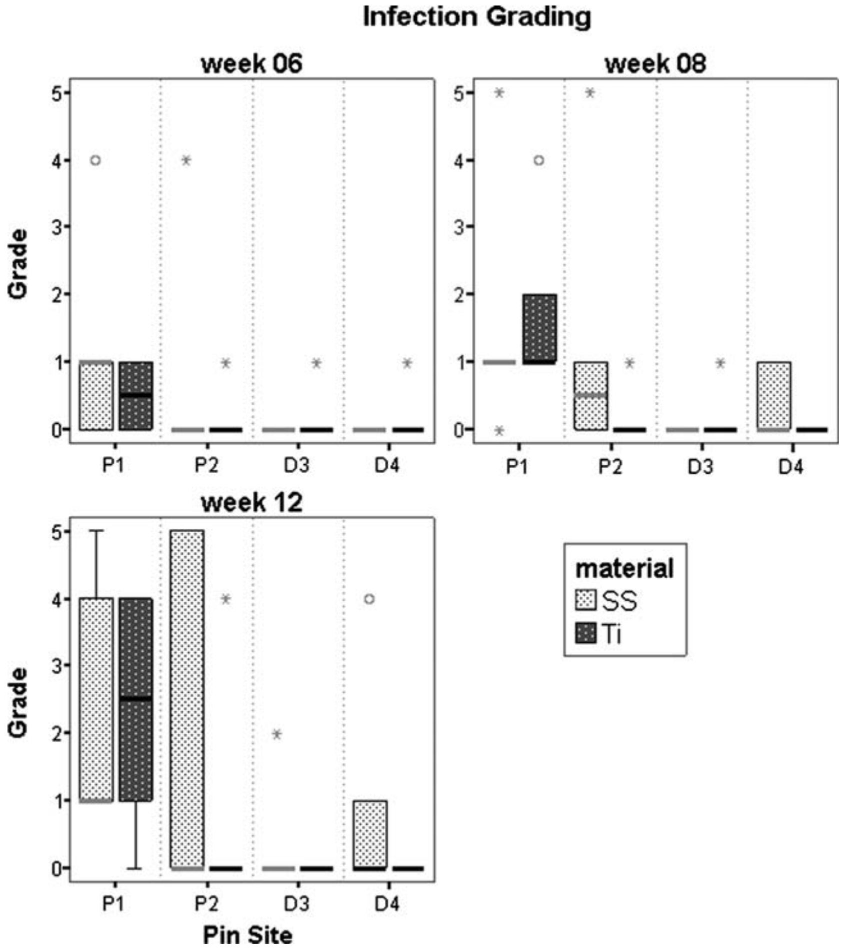

Figure 2. Box plots showing the radiolucency grading at week 6 (top left), week 8 (top right), week 12 (bottom) for both materials at all pin sites. The median is represented by the bold line and the box indicates the interquartile range. The whiskers show the range of data. A circle indicates an outlier and an asterisk an extreme value.

an effect of pin site was significant, stratified Wilcoxon, also known as van Elteren, tests (Mathematica) were used to examine if there was an effect for results blocked by pin site at each time point. Otherwise, the results from all four pin sites were pooled and Wilcoxon tests (Mathematica) were used to examine for effects at each time point. The level of significance was set at $p < 0.05$. To compare the extraction torques between the two groups, a General Linear Model analysis of variance and Tukey HSD post-hoc test were used with the level of significance set at $p < 0.05$ (SPSS, SPSS Schweiz AG, Zürich, Switzerland).

Results

Two of the animals in the Ti group that were designated for pin-filled, qualitative histological analysis had to be sacrificed early (1 at 2 weeks, the other at 3 weeks) due to breakage of the P2 pin at the location of the periosteum of the near cortex. This failure was caused by the lack of integrity of the clamp holding P1 to the fixator. This clamp loosened and allowed P1 to slip, causing P2 to be overloaded. Both of these animals were excluded from the study. The quantitative clinical and biomechanical results were analyzed only for the sheep in each group that were designated for pin removal at sacrifice ($n = 6$ for both groups).

Clinical Results

The radiographical analysis showed only small non-significant differences in radiolucency between the two materials. Early in the observation period, the radiolucent halo about the SS pins appeared more severe grade at 6 weeks but this difference lessened with time (Figure 2). Some sequester formation was only evident around SS pins. At 6, 8 and 12 weeks, the Friedman test identified a significant effect of pin site at all three time points ($p < 0.001$). The stratified Wilcoxon Test found only a trend for lower radiolucency grades for Ti than for SS at 6 weeks ($p = 0.13$), which diminished in further weeks (8 weeks: $p = 0.33$; 12 weeks: $p = 0.22$).

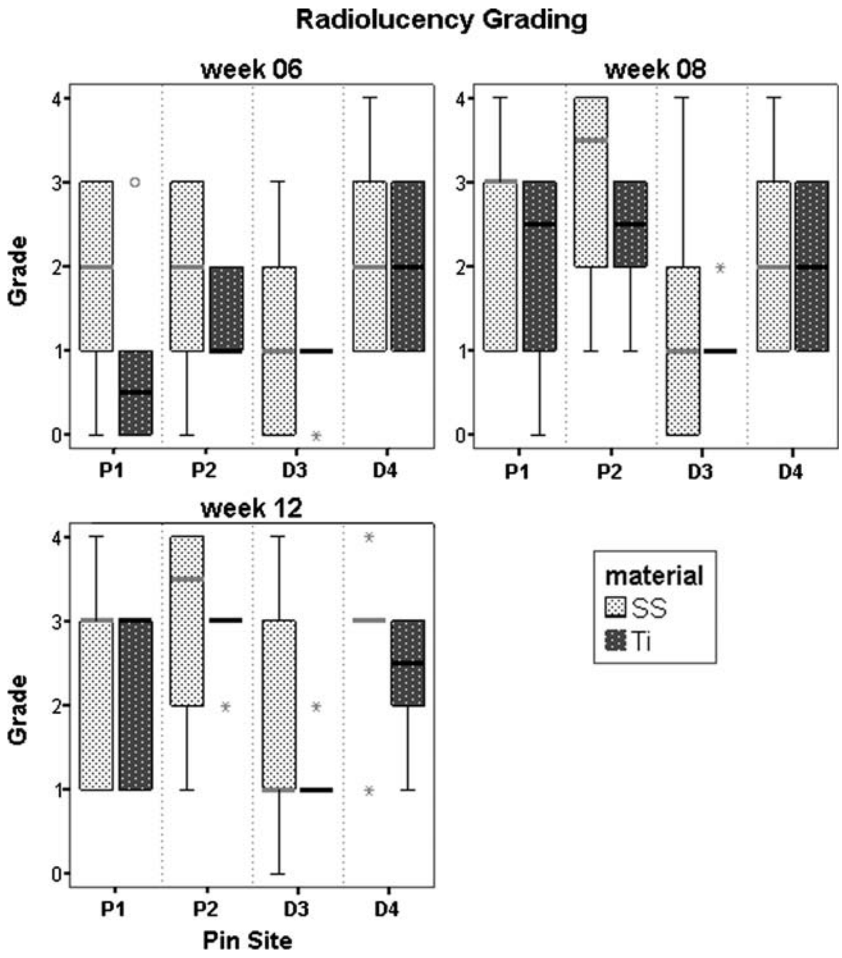

Figure 3. Box plots showing the clinical infection grading at week 6 (top left), week 8 (top right), week 12 (bottom) for both materials at all pin sites. The median is represented by the bold line and the box indicates the interquartile range. The whiskers show the range of data. A circle indicates an outlier and an asterisk an extreme value.

There was no difference in the clinical appearance of irritation/infection between pin materials in the early observation period (Figure 3). Although, Ti appeared to show less irritation/infection at sacrifice, the stratified Wilcoxon Test could only show a trend for higher grades of irritation/infection at 12 weeks for SS ($p = 0.14$) and no statistically significant differences earlier (6 weeks: $p = 0.44$; 8 weeks: $p = 0.55$). Seven pin sites with a high grade irritation/infection at sacrifice were sampled for bacteriology. Five SS and two Ti pin sites were cultured. All swabs exhibited growth of staphylococcus intermedius or staphylococcus epidermidis. Both microorganisms are members of the normal flora of skin and mucous membranes.

Biomechanical Results

The bending stiffness measurements showed a wide variation within the two groups. Only 3 of the 12 sheep exhibited progressive, timely gap osteotomy healing (Table 3). With respect to delays and interruptions in healing, there was no difference between the groups.

Complications with the data logger resulted in the loss of insertion torque data for five of the six sheep in the SS group that were designated for pin removal at sacrifice. This resulted in insertion torque data for only four pins and this would not be sufficient for statistical analysis. However, insertion torque data were also available for the remaining two sheep in the SS group whose pins were not removed at sacrifice. Inclusion of these data allows for a baseline to be established for the SS insertion torques. The mean insertion torque and standard error for pins in the SS group ($n = 12$) was 3.60 ± 0.40 Nm. The data were insufficient to determine any variation in pin location. Insertion torque data were lost for only five pins in the Ti group and it was not necessary to include data for the animals that were intended for qualitative analysis. For the Ti group ($n = 19$), the mean insertion torque was 0.91 ± 0.15 Nm and no differences were found for different pin sites.

On extraction, data from three SS pins and one Ti pin were lost. Due to the loss of insertion torque data, the extraction torques were analyzed as absolute values. For both groups, pins at the different sites had different extraction torques, with significantly higher extraction torque required to remove pins at site D3 than at P1 (p = 0.001) and D4 (p = 0.002). Statistical analysis of the pins blocked according to site showed no difference between pin materials (Figure 4).

Histological Results

Analysis of the pin-filled specimens showed little difference in the tissue reaction to the implant materials. Good bone apposition up to the implant, high porosity and active bone remodeling were seen for both groups. There was a similar abundance of osteoblasts, however a higher abundance of osteoclasts was found around SS pins. Fluorescent analysis showed no difference in the history of bone remodeling between the two materials. The bone growth observed up to both pin surfaces was distance osteogenesis and resulted in the interposition of a fibrous tissue layer between the bone and the implant (Figure 5). More reactionary periosteal bone was seen around Ti pins. Inflammatory cells in the form of granulocytes and giant cells were found only around one SS pin.

Specimens without pins and with a radiographical grading of (0 or I) and (II or III) were grouped together. A high porosity was present for all radiolucency grades. Periosteal reactionary bone formation increased around pins with a higher radiolucency grading. Low radiolucency grades corresponded to good apposition of the bone to the implant. The quality of bone apposition decreased until complete resorption of the bone at the pin surface was seen for the highest radiolucency grade. Osteoblasts and osteoclasts were present for all grades of radiolucency, and the abundance of these cells increased with increasing radiolucency grade. Specimens with a clinical infection grade of (0 or I), (II or III) and (IV or V) were grouped together. Granulocytes were only present for the highest infection grades.

Table 3. Progression of osteotomy gap healing for animals within each pin type.

Healing progression	SS	Ti
Normal	2	1
Slight delay	3	2
Moderate delay		3
Interrupted	1	

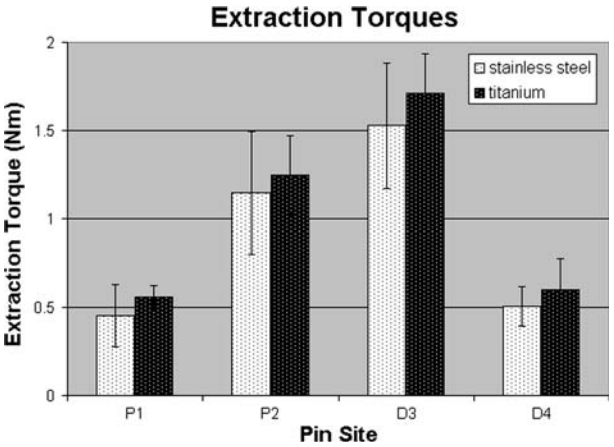

Figure 4. Mean extraction torque values (and SE) for SS and Ti at all pin sites.

Discussion

This study compared SS to Ti pins on reducing pin track irritation/infection and pin loosening in a loaded, ovine model by assessing objective biomechanical data and radiographical, infection and histological observations. Hydroxyapatite and calcium phosphate coated external fixation pins have been shown to increase osseointegration and reduce infection [12, 24]. However, these coated pins have not become standard clinical implants because they are expensive, rendering coated pins inaccessible in many external fixation scenarios. Hence, only SS and Ti were compared in this study.

This model incorporated a 6 mm osteotomy gap to simulate a fracture. The bending stiffness measurements showed that in most cases, complete healing of the facture gap did not occur during the 12 week observation period and that the healing progression did not vary between the groups. This ensured that the pins of both materials were loaded throughout the experiment and thus, this model approximates a comminuted unstable fracture with slow healing.

During the experiment, two of the Ti animals were excluded due to pin failure at P2. Analysis showed the most likely reason was lack of integrity of the experimental clamp. After the clamps were replaced, no further failures occurred. Also, no SS pin failures occurred due most likely to SS's higher strength. Furthermore, this problem is less likely to occur with a clinically approved fixator/clamp system. The exclusion of the two Ti animals did not impair the outcomes from this study. The role of these animals was to provide supportive histological analysis and the one remaining Ti animal was sufficient for this purpose.

In this study, pin loosening was assessed by examining the radiographical appearance of bone resorption around the pins. Although radiographical grading is not the most sensitive or most objective method for assessing osteolysis around the pins, it is the measure most often used clinically. Perhaps this was the reason that only a trend for less bone resorption with Ti pins during the early observation period was detected. However, because there was no difference between the two materials later on, there probably is no real clinical difference in terms of osteolysis around either pin type. This finding was also supported by (1) the qualitative histological analysis that showed active bone remodeling at the bone/implant interfaces for both materials and (2) similar healing rates of the gap osteotomies.

The radiolucency grading scheme used in this study was a good indication of bone apposition to the pin and reactionary periosteal bone growth around the pin. Higher grades of radiolucency were related to less bone apposition and larger periosteal bone growth observed histologically. These findings are in accordance with previous studies [25]. Radiolucency is an indication of resorbed bone around the implant, creating a weak bond between the bone and the implant. This weak bond is reflected by a poor fit of the bone to the screw threads. A weak bond allows for micro-motion of the pin with respect to the bone. Hence, new extra cortical bone is created in an attempt to stabilize the pin. However, the radiolucency grading scheme was not a good indicator for porosity as seen in previous studies [25]. This was because the radiolucency grading scheme was based on measuring the absence of cortical bone around the pin, rather than measuring the variation in the radiographical intensity around the pin. As porous bone contains some cortical bone, this radiolucency grading scheme would not be sensitive to varying severity of porosity.

Insertion torque is a measure of the friction between the pin and biological tissue. The insertion torque for the SS group was higher than for the Ti group. In this study, the pin holes were drilled to a smaller diameter than the pin to ensure radial preloading of the pin. Under these conditions, there is a higher resistance to turning in SS pins due to their higher stiffness combined with the interference fit, resulting in greater friction and a higher insertion torque.

The peak extraction torque is a measure of pin osseointegration. After a 12 week observation period, there would be no friction effect between the pin and bone due to the radial preload as the bone in the regions of high stress would have been remodeled [26]. Hence, as the SS and Ti pins have identical geometry, the extraction torque values could be analyzed as absolute values. This analysis found no difference in torque values between the two materials. This suggests that after 12 weeks implantation, there is no difference in the osseointegration ability of the two materials. This was supported by the analysis of bone apposition to the screw threads showing no difference between the groups at the end of the observation period.

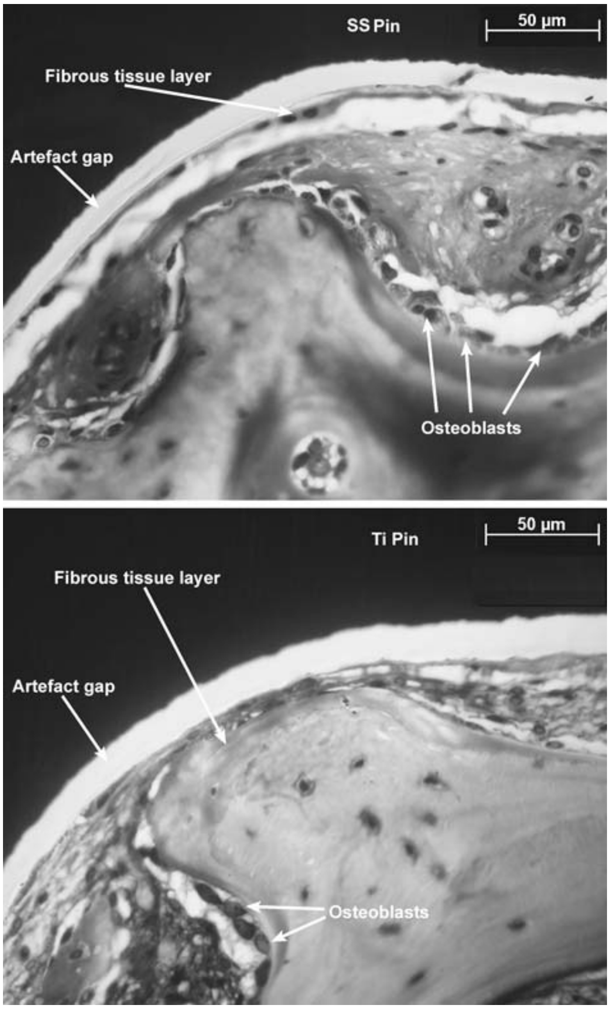

Figure 5. Un-decalcified PMMA embedded mid-transverse section of SS (top) and Ti (bottom) pin-filled sites 12 weeks after insertion showing distance osteogenesis of bone growth up to the pin surface (toluidine blue and eosin, scale bar 50 µm). During histological preparation, the biological tissue shrank away from the implant material. This produced an artifact gap between the screw threads and the bone that was visible on all slides for both materials.

The nature of bone growth for Ti, as a bioinert material, was expected to be contact osteogenesis with new bone formation originating from the implant surface [11]. The Ti specimens did show new bone growth against the implant surface, however, the osteoblasts responsible for this bone formation were situated a small distance away from the implant, so bone growth was directed towards the surface rather than originating from it. The interposition of a non mineralized, organic layer resulted in distance osteogenesis. Moroni et al. [12] found similar results for tapered Ti external fixation pins. This suggests that the tissue reaction to loaded Ti implants results in distance osteogenesis, as seen for SS.

There was no significant difference in irritation/infection between the pin materials up to 12 weeks. The grading scheme used in this study is not directly a measure of infection and merely indicates the level of soft tissue irritation. Hence, for those pin sites that exhibited pus, as opposed to clear fluid, exudation, bacterial swabs were taken. At post-mortem (week 12), a trend for more infection about SS pins was visible. This was reflected in that 5 SS versus 2 Ti pin-sites exuded pus. Of these seven pin sites, all exhibited bacteria consistent with normal ovine skin flora. Histologically, reactionary cells were only slightly more prolific in tissue from animals with SS pins.

The histological assessment of the infection grading scheme used in this study found reactionary cells indicating deep pin track infection for clinical infection grades of IV and V. This suggests that only persistent clinical pin track infections with radiographical evidence of bone resorption will develop an inflammatory reaction in the bone. Less severe pin track infections are contained within the superficial soft tissue.

In conclusion, this study did not find a clinically relevant substantial benefit of using either SS or Ti Schanz screws with respect to pin loosening or irritation/infection in a loaded, external fixation ovine model. Histological observations were consistent with radiological grading of osteolysis, mechanical assessment of pin osseointegration and clinical grading of irritation/infection.

Acknowledgments

The authors would like to thank Urs Schlegel and Dr. Geoff Richards for their consultation time and the Robert Mathys Foundation for providing the implants.

References

1. Jukema GN, Hierholzer G. Geschichte und Entwicklung der Fixateur-Externe-Osteosynthese. OP-J 1997;13:4–9.
2. Samir M, Wudbhav SN, Christopher BT. External fixation of the pelvis and extremities. Lippincott Williams & Wilkins, Philadelphia, 2004.
3. Egger EL. External skeletal fixation - general principles. In: Slatter DH (Ed.Textbook of small animal surgery. Saunders, Philadelphia 1993, pp 1641–56.
4. Egger EL. Complications of external fixation. A problem-oriented approach. Vet Clin North Am Small Anim Pract 1991;21:705–33.
5. Green SA. Pin tract infection. In: Charles C Thomas, ed. Complications of external skeletal fixation. AnonymousSpringfield, 1981:12–30.
6. Harari J. Complications of external skeletal fixation. Vet Clin North Am Small Anim Pract 1992;22:99–107.
7. Schatzker J, Horne JG, Sumner-Smith G. The effect of movement on the holding power of screws in bone. Clin Orthop 1975;111:257–62.
8. Johnson D, Tucci M, McGuire R, Hughes J. Evaluation of the biomaterial-interface of screw threads in patients having clinical pain. Biomed Sci Instrum 1996;32:127–33.
9. Pettine KA, Chao EY, Kelly PJ. Analysis of the external fixator pin-bone interface. Clin Orthop 1993;293:18–27.
10. Bolz RE, Tuve GL. CRC handbook of tables for applied engineering science. The Chemical Rubber Co, Florida, 1973.
11. LeGeros RZ, Craig RG. Strategies to affect bone remodeling: osteointegration. J Bone Miner Res 1993;8:S583–96.
12. Moroni A, Toksvig-Larsen S, Maltarello MC, et al. A comparison of hydroxyapatite-coated, titanium-coated, and uncoated tapered external-fixation pins. An *in vivo* study in sheep. J Bone Joint Surg Am 1998;80:547–54.
13. Moroni A, Vannini F, Mosca M, Giannini S. State of the art review: techniques to avoid pin loosening and infection in external fixation. J Orthop Trauma 2002;16:189–95.
14. Arens S, Schlegel U, Printzen G, et al. Influence of materials for fixation implants on local infection. An experimental study of steel versus titanium DCP in rabbits. J Bone Joint Surg Br 1996;78:647–51.
15. Eulenberger J, Steinemann SG. [Removal torques of small screws of steel and titanium with different surfaces]. Unfallchirurg 1990;93:96–9.
16. Sun C, Huang G, Christensen FB, et al. Mechanical and histological analysis of bone-pedicle screw interface *in vivo*: titanium versus stainless steel. Chin Med J (Engl) 1999;112:456–60.
17. Clary EM, Roe Sc . Enhancing external skeletal fixation pin performance: consideration of the pin-bone interface. Vet Comp Orth Traumatol 1995;8:1–8.
18. Lill CA, Hesseln J, Schlegel U, et al. Biomechanical evaluation of healing in a non-critical defect in a large animal model of osteoporosis. J Orthop Res 2003;21:836–42.
19. Augat P, Margevicius K, Simon J, et al. Local tissue properties in bone healing: influence of size and stability of the osteotomy gap. J Orthop Res 1998;16:475–81.
20. Claes L, Augat P, Suger G, Wilke HJ. Influence of size and stability of the osteotomy gap on the success of fracture healing. J Orthop Res 1997;15:577–84.
21. Rahn BV, Bacellar FC, Trapp L, Perren SM. [A method for morphometry of bone formation using fluorochromes (author's transl)]. Aktuelle Traumatol 1980;10:109–15.
22. Checketts RG, Otterburn M. Pin track infection: Definition, prevention, incidence. Suppl Internat J Orth Trauma 1993;3:16–8.
23. Jowsey J, Phil D, Kelly PJ, et al. Quantitative microradiographic studies of normal and osteoporotic bone. J Bone Joint Surg Am 1965;47:785–806.

24. Pommer A, Muhr G, David A. Hydroxyapatite-coated Schanz pins in external fixators used for distraction osteogenesis: a randomized, controlled trial. J Bone Joint Surg Am 2002;84-A:1162–6.
25. Aro HT, Markel MD, Chao EY. Cortical bone reactions at the interface of external fixation half-pins under different loading conditions. J Trauma 1993;35:776–85.
26. Hyldahl C, Pearson S, Tepic S, Perren SM. Induction and prevention of pin loosening in external fixation: an *in vivo* study on sheep tibiae. J Orthop Trauma 1991;5:485–92.

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