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# Assessment of Xenogenic Bone Plate and Screw using Finite Element Analysis

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**Abstract :** The aim of this study was to evaluate the biomechanical behavior of xenogenic bone plate system (equine bone) using a three-dimensional finite element ulna fracture model. The model was used to calculate the Von Mises stress (VMS) and stress distribution in fracture healing periods with metallic bone plate and xenogenic bone plate systems, which are installed while the canine patient is standing. Bone healing rate (BHR) (0%) and maximum VMS of the xenogenic plate was similar to the yield strength of equine bone (125 MPa). VMS at the ulna and fracture zones were higher with the xenogenic bone plate than with the metallic bone plate at BHRs of 0% and 1%. Stress distributions in fracture zone were higher with the xenogenic bone plate than the metallic bone plate. This study results indicate that the xenogenic bone plate may be considered more beneficial for callus formation and bone healing than the metallic bon plate. Xeonogenic bone plate and screw applied in clinical treatment of canines may provide reduced stress shielding of fractures during healing.

***Key words* :** Finite element analysis, xenogenic bone plate, xenogenic bone plate screw, Von Mises stress, ulna fracture model.

## Introduction

Metallic bone plates and screws are widely used for the treatment of bone fractures in both human and veterinary medicine (7,17). Metallic internal fixation hardware provides excellent reduction of the bone fragment and has the necessary strength to stabilize and support the fracture, allowing early mobility of the limb. Metallic bone plate made of stainless steel, cobalt-chromium and titanium alloys are commonly used to treatment of bone fracture. However, the metallic plates have an elastic modulus (110-220 GPa) at least 10 times greater than that of bone (17-24 GPa) (12). Numerous studies have established that these metallic plates interfere with normal bone physiology by causing bone loss under the plate. The long-term effect of using the metallic plate is bone remodeling and loss due to the changed stress-condition induced by metallic internal fixation (6,16,18). Although their appropriate mechanical properties of certain popular plate designs have been reported, the overall clinical outcome remains pessimistic.

The importance and high cost of treating bone fractures has promoted the development of non-invasive methods of assessing fracture risk and prevention. Finite element (FE) analysis of skeleton, a very powerful tool for biomechanical research, involves examination of the regions where the fracture or healing initially appears, and the forces and orientations needed to produce them (2,10,13,14). FE analysis is increasingly used in the design and evaluation of bone plates and screws to overcome the major weaknesses of current fixation devices: fatigue failure of the device and stress-shielding of the bone.

Xenogenic cortical bones are useful for enhancing bone repair and reconstructive bone defect, and have been advocated due to their reliable incorporation and remodeling with fracture sites (1,9,20). Additionally, the mechanical strength and volume of xenogenic bone make its use for interference internal fixation devices possible (11,15,20).

In order to evaluate the newly developed bone plate with xenogenic bone plate and screw, we presently compared it with metallic bone plate by investigating biomechanical behavior in critical parts of the bone-plate systems under the static loading condition of canine standing weight.

## Material and Methods

### Design and Fabrication of Xenogenic Bone Plate and Screw

The xenogenic bone plates and screws were designed to the dimensions of standard Dynamic Compression Plate (DCP) of the Arbeitsgemeinschaft für Osteosynthesefragen (AO) institute. The plates were rectangular, 48 mm in length, 10 mm in width and 3 mm thick. The screws were conical with a diameter of 3.5 mm, length of 13 mm and head diameter of 6 mm. The metallic plates and screws had the same size as the xenogenic bone plates and screws (Fig 1).

### FE Analysis

The mean weight (average 11.2 ± 1.34 kg) and ulna diameter (inner and outer diameters of 4 mm and 7 mm, respectively) of 10 beagle dogs were used for this study. Three-dimen-

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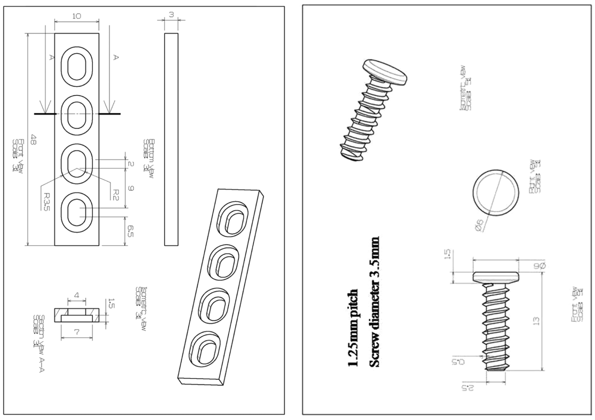


**Fig 1.** Shape and dimension of xenogenic bone plates and screws.

sional models of the bone-plate systems were analyzed using ABAQUS 6.7-1 software. Canine bone (ulna) and fracture sites were defined as smooth, hollow cylindrical geometric shapes. The bone marrow was thought not to bear a load. The bone model taken into account has a ratio of 2/3 between internal and external diameters (8). Metallic bone plates were dimensioned using a four-hole DCP. Screws were taken as 3.5 mm cortical screws and modeled as completely fixed to bone. It was assumed that a 1 mm-thick transverse fracture between intact bone fragments existed. The bone material was assumed to be isotropic and uniform throughout the cortical bone, and was made by the cortical bone throughout with a Young's modulus of 15 GPa and poisson ratio of 0.3.

The callus was assumed to bridge the fracture gap. The callus material was assumed to be isotropic and homogenous having E = 0.01 GPa at a bone healing rate (BHR) of 1%, 15 GPa = 15000 MPa at a BHR of 75% (BHR 0%: 0 MPa, BHR 1%: 150 BHR, callus 50%: 7500 MPa, BHR 90%: 13500 MPa) (Benli et al. 2008). Compression, which was considered as the loading condition of the problem, was thought to be caused by the standing weight of the canine patient. For an 11 kg weight canine, the approximate load applied to the ulna cross-section was calculated as:

$$F = 11\ \text{Kgf} \times 9.81\text{N} = 107.9\text{N}$$
$$A = \text{Pi} / 4 \times (7^2 - 4^2) = 25.9\ \text{mm}^2$$
$$P = 107.9\text{N} / 25.9\ \text{mm}^2 = 4.2\ \text{MPa}$$

Material properties were defined for each element are given in Table 1. The area under the lower bone segment was selected as the boundary condition in the x, y and z directions. The FE model of bone-plate system is shown in Fig 2.

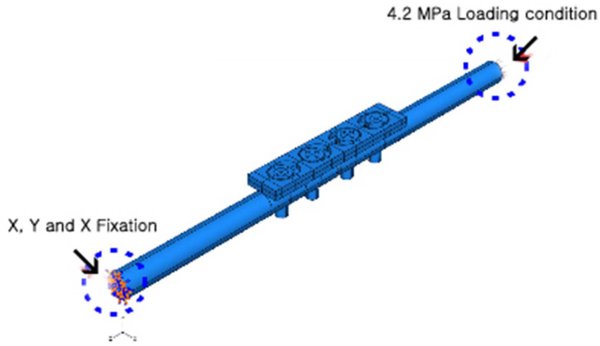


**Fig 2.** The finite element model of bone-plate system. Compression, which was considered as the loading condition of the problem, is thought to be caused by the canine patient weight while standing up (4.2 MPa). The area under the lower bone segment is selected as boundary condition in x, y and z direction.

## Results

FE analyses of bone plate system assembly were conducted for the aforementioned implant materials. The Von Mises Stress (VMS) for FE analyses of xenogenic bone plate and screw are shown in Figs 3-5. The maximum stress in the plate was exerted in the screw hole located close to the fracture site. The VMS of the metallic and xenogenic plates at a BHR of 0% were 112.6 MPa and 112.3 MPa, respectively. The stress displacement was 0.115 mm and 0.557 mm, respectively. At a BHR of 50%, the VMS for metallic and xenogenic plates of bone period were 13.29 MPa and 6.002 MPa, respectively. Meanwhile, the stress displacement was 0.023 mm and 0.024 mm, respectively. The results are summarized in Tables 2 and 3 and Fig 6. As shown in Fig 7, the compressive stress was determined by selecting the nodes from the FE analysis model. Compressive stress was 0.2 MPa in the metallic bone plate and 0.2 MPa in the xenogenic bone plate. At a BHR of 1%, the xenogenic bone plate provided more compressive stress than metallic bone plate in fracture zone (Fig 8). At a BHR of 50%, the neutral axis of the xenogenic bone plate moved to the bone more than that of metallic bone plate (Fig 9). Similar results were obtained at a BHR of 90% (Fig 10).

## Discussion

By the BHR, the VMS and displacement at the fracture interface were analyzed to evaluate the effect of the metallic

**Table 1.** Material properties of the elements

| | | Young's modulus (E) | Poisson's ratio | Yield strength | Ultimate strength |
|---|---|---|---|---|---|
| Ti6A14V* | | 110 GPa | 0.3 | 800 MPa | - |
| Bone | Equine* | 20 GPa | 0.3 | 125 MPa | - |
| | Canine* | 15 GPa | 0.3 | - | 455 MPa (F),<br>584 MPa (M) |

* (3)

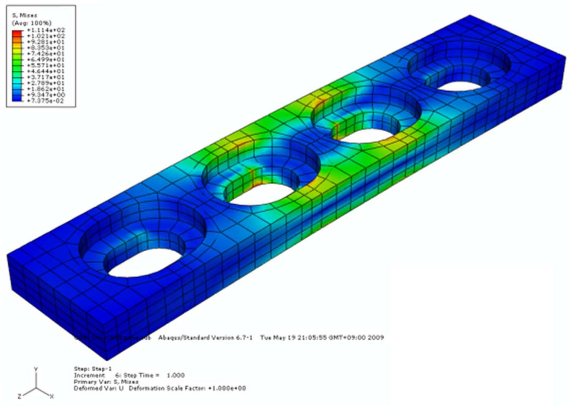

**Fig 3.** The Von Mises stress distribution of xenogenic bone plate at the bone healing rate (0%). The maximum stresses in plate are in the near to the screw hole located close to fracture site.

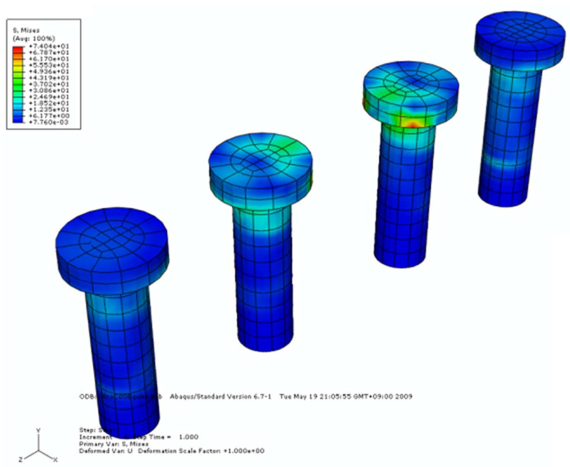

**Fig 4.** The Von Mises stress distribution of xenogenic bone screw at the bone healing rate (0%). The maximum stresses in screw are in the screw neck located close to fracture site.

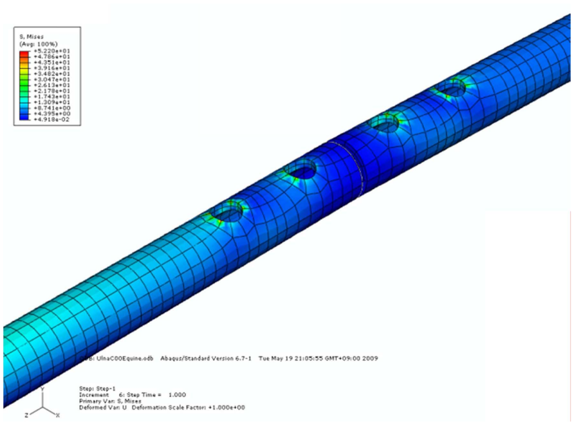

**Fig 5.** The Von Mises stress distribution of canine bone at the bone healing rate (0%). Maximum stresses of bone are observed at the screw holes due to the concentrated contact stresses.

bone and xenogenic bone plates. The xenogenic bone plate displayed a similar stress response to the metallic bone plate.

**Table 2.** The maximum Von Mises stress values of metallic bone plate system by the fracture healing rate

| | BHR *0%* | BHR *1%* | BHR *50%* | BHR *90%* |
|---|---|---|---|---|
| | Maximum Von Mises Stress (MPa) | | | |
| Plate | 112.6 | 41.99 | 13.29 | 13.23 |
| Screw | 75.42 | 26.17 | 13.50 | 13.48 |
| Ulna | 17.71 | 15.77 | 14.92 | 14.90 |
| Fracture zone | - | 3.281 | 4.977 | 5.613 |

BHR: Bone Healing Rate

**Table 3.** The maximum Von Mises stress values of xengenic bone plate system by the fracture healing rate

| | BHR *0%* | BHR *1%* | BHR *50%* | BHR *90%* |
|---|---|---|---|---|
| | Maximum Von Mises Stress (MPa) | | | |
| Plate | 112.3 | 11.95 | 6.002 | 5.977 |
| Screw | 74.47 | 9.375 | 9.852 | 9.852 |
| Ulna | 38.57 | 17.86 | 16.61 | 16.59 |
| Fracture zone | - | 4.608 | 4.915 | 5.489 |

BHR: Bone Healing Rate

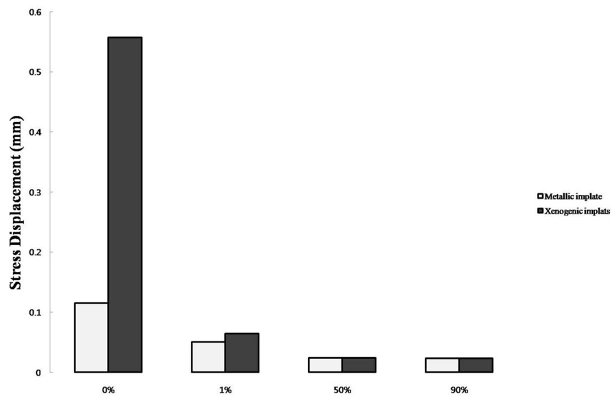


**Fig 6.** Stress Displacement of metallic bone plate system and xengenic bone plate system by the fracture healing rate.

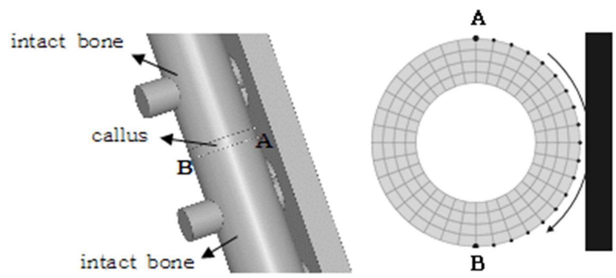


**Fig 7.** Stress values at the fracture interface are determined by selecting the node attached to fracture surface through arrow.

At 0% BHR, the stress in the xenogenic bone plate occurred mainly (112.3 MPa) around the middle of the shaft. The VMS of the xenogenic plate was similar to the Yield strength of

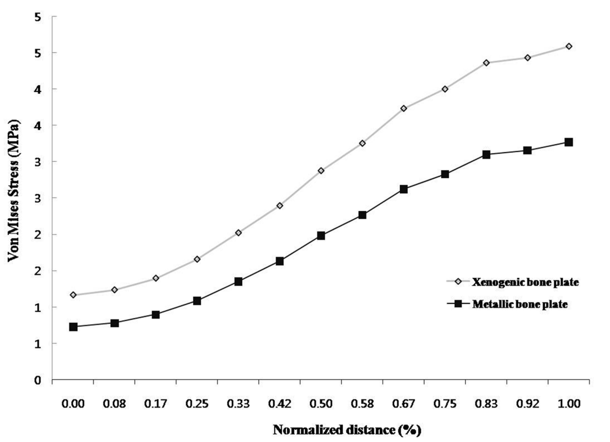


**Fig 8.** Stress distribution measured around the fracture model with 1% bone healing rate on each bone plate system around the fracture region.

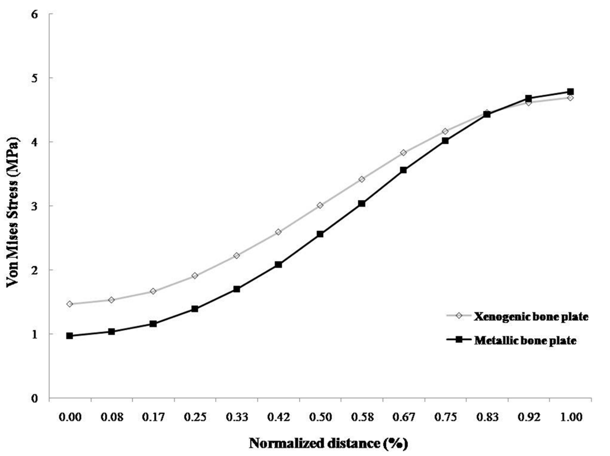


**Fig 9.** Stress distribution measured around the fracture model with 50% bone healing rate on each bone plate system around the fracture region.

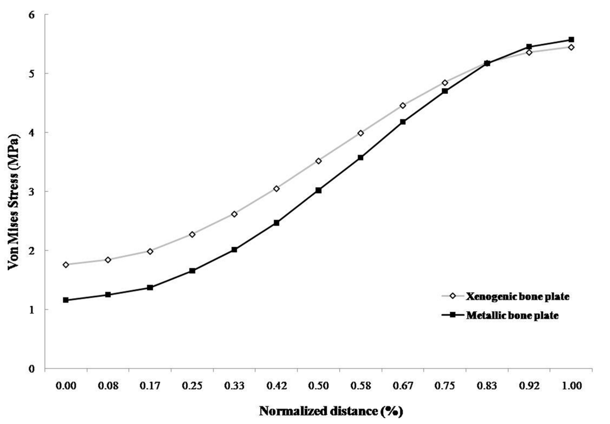


**Fig 10.** Stress distribution measured around the fracture model with 90% bone healing rate on each bone plate system around the fracture region.

equine bone (125 MPa). Indications of stress can occur to the breaking point in a xenogenic bone plate. In dogs, during slow walking the ground reaction force equals 30% of the body weight with each forelimb and 20% of the body weight with each hindlimb. However, the ground reaction force may increase to five times or more of body weight at a fast trot or run, or on landing from a jump (17). Hence, for a xenogenic bone plate, postoperative immobilization is needed during the initial healing periods. At BHRs of 1%, 50% and 90%, this maximum loading resulted in VMS values below the Yield strength of equine bone and metallic material. This result indicates that xenogenic bone plate and screw may be used for the treatment of canine bone fracture.

Numerous studies have shown that these rigid metal plates contribute to bone mass loss due to the stress shielding of the bone beneath the plate. Mechanical changes due to internal fixation result in the reduction in cortical bone structure by the thinning of the cortex, rather than by a reduction in bone substance mechanical properties (19,22). The latter study compared the results obtained with a rigid metal plate and a less rigid composite plate. After 9 and 12 months of plate application, a significantly increased amount of bone atrophy was seen on the rigid plate side. Femurs showed bone to similar mechanical properties, but different structural properties (21).

VNS contours showed that the maximum stresses in the plate were near to the screw hole located close to fracture site; the stress value was 112.6 MPa for the metallic bone plate and 112.3 MPa for the xenogenic bone plate. There is a need improve the xenogenic plate design so that will not fail at the screw hole near to fracture site. Maximum bone content at the screw holes reflects the concentrated contact stresses in this region.

Presently, the VNS at ulna and fracture zone were higher with the xenogenic bone plate than with the metallic bone plate at 0% and 1% BHR. VNS of ulna and for the metallic and xenogenic plates at 0% BHR were 17.71 MPa and 38.57 MPa, respectively, and 26.17 MPa, 17.86 MPa and 3.281 MPa, 4.608 MPa, respectively, at 1% BHR. The VMS at 50% BHR was similar to that for 90% BHR. Based on the results obtained at 0% and 1% BHR, xenogenic bone plate may be considered as more beneficial for callus formation and bone healing compared to the metallic bone plate.

Research is ongoing aimed at incorporating bioabsorbable materials into plate designs and uses. The designs are based on the hypothesis that suitable stress of host bone during the fracture healing can be attained with low stress shielding of the fracture zone (4,5,10,14).

The stress distributions of bone plate system change during healing. The present results show that, for a given load, stress distributions in the fracture zone are higher swith the xenogenic bone plate than with the metallic bone plate. This higher stress in bone could aid growth of the callus. It is apparent that the xenogenic bone plate system provides less stress-shielding to bone, and offers higher stresses at the fracture interface that improves the fracture healing process in comparison with the metallic bone plate system. Therefore, the xenogenic bone plate system verified by FE analysis may be applied to fix bone fracture as an internal fixation material.

## Conclusion

In summary, a three-dimensional FE model was used to evaluate the VMS and stress distribution in fracture healing periods with the metallic bone plate and xenogenic bone plate systems. The maximum VMS at ulna and fracture zones were higher with xenogenic bone plate than with metallic bone plate at BHRs of 0% and 1%. Stress distributions in fracture zone were higher with the xenogenic bone plate than with the metallic bone plate. Our esults from FE analysis establish that the xeonogenic bone plate and screw applied clinical treatment will offer reduced stress shielding of canine fractures during their healing.

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