FRACTURE OF VERTEBRAL BONE GOTTEN SURGICAL SCREW INSERTION

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ABSTRACT

On spinal surgery, screws execute fixation of the device to vertebral bone mainly. Vertebral bone is composed of cortical bone and cancellous bone. The cortical bone is located on the surface whereas cancellous bone is located in the interior. The cancellous bone has spongy structure and its strength is about one tenth of that of cortical bone. When a screw is inserted to a vertebra, cortical and cancellous bones sustain the screw. The screw dimension is decided as to be average value of surgical screw on the market. Screw was inserted to a bovine lumbar vertebra through a plate with a screw hole, and the binding force between plate and bone was measured. Microstructure of bone before and after the test was examined using reconstructed 3D image by a micro CT machine. The solid model FEM analysis of the bone around the screw was done. The obtained binding forces by experiment and by FEM analysis have good correlation each other. Investigating fractured bone region gotten by micro-CT and von Mieses stress contour by FEM analysis, the fracture is supposed to be induced at the stress excess area of the solid FEM model. And it was suggested that a micro crack initiated in cancellous bone does not affect broader region because it is locally trapped by porous microstructure of the bone.

KEYWORDS

Fracture of cancellous bone, Surgical screw, Micro-CT, FE analysis, von Mieses stress.

INTRODUCTION

On spinal surgery, screws execute fixation of the device to vertebral bone mainly. Vertebral bone is composed of cortical bone and cancellous bone. The cortical bone is located on the surface whereas cancellous bone is located in the interior. The cancellous bone has spongy structure and its strength is about one tenth of that of cortical bone. When a screw is inserted to a vertebra, cortical and cancellous bones sustain the screw. The mechanical role of cortical and cancellous bones on the screw fixation was investigated relating to the cancellous bone fracture [1,2].

MATERIAL AND METHOD

The screw dimension (Figure1) is decided as to be average value of surgical screw on the market1, which is as follows. The effective screw length is 40-mm, major diameter is 6-mm, minor diameter is 4-mm and the screws with different pitches were prepared to test what pitch has the largest binding force between them. The pitches are 2-mm, 3-mm, 4-mm and 5-mm. Specimen of longitudinal direction (long.) is tested applying load parallel to longitudinal directions of bone and specimen of transverse direction (trans.) is done to transverse direction of bone. Material of the screw is stainless steel. Table 1 gives the material property of bone gotten by our experiment. Screw was inserted to a bovine lumbar vertebra through a plate with a screw hole, and the binding force between plate and bone was measured(Figure 2). . Used machine is a material testing machine, Servo-pulsar EHF-ED5 manufactured by Shimadzu Co., Japan (Figure 3a).

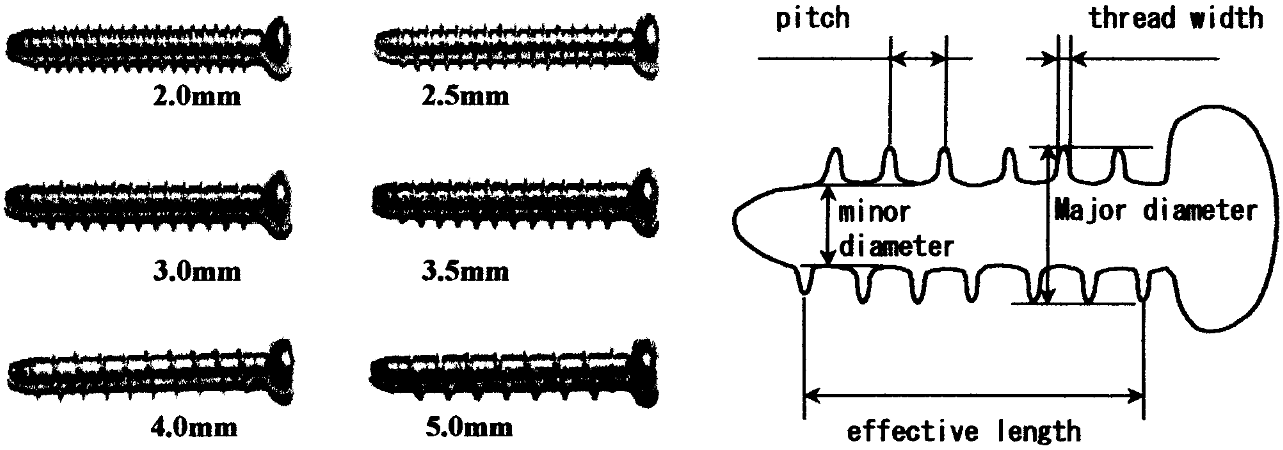


Figure 1: Screws used for of experiment

TABLE 1
MATERIAL PROPERTY OF BOVINE VERTEBRAL BONE [3]

Material property of vertebral bone	Young's modulus (MPa)		Ultimate strength (MPa)		Ultimate strain (mili-strain)		Fracture toughness (MPa(m**0.5))	
Specimen direction	long.	trans.	long.	trans.	long.	trans.	long.	trans.
Cortical bone	8038	3282	31.99	15.64	8.91	7.50	1.8	1.31
(SD of Cortical bone)	(3924)	(1298)	(6.73)	3.85	(3.42)	(4.31)	(0.53)	(0.48)
Cancellous bone	820	498	4.49	1.89	11.10	15.90	0.23	0.37
(SD of Cancellous bone)	(443)	(428)	(1.60)	1.08	(5.45)	(6.30)	(0.12)	(0.25)

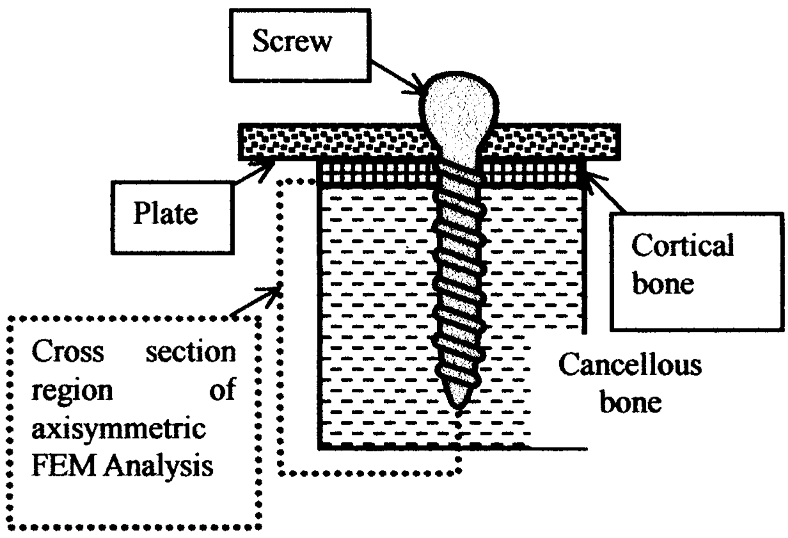
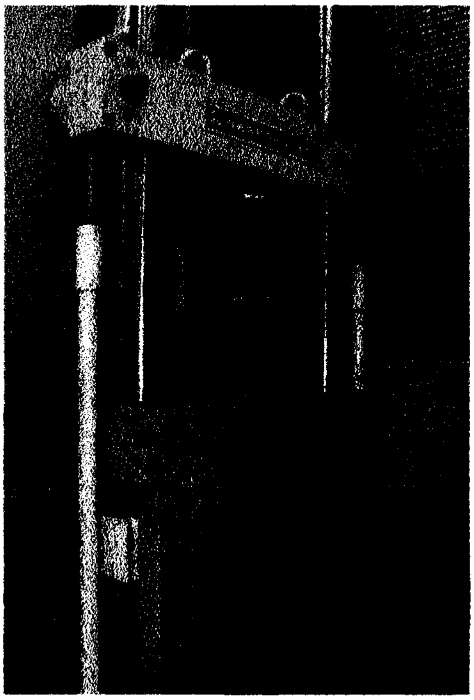


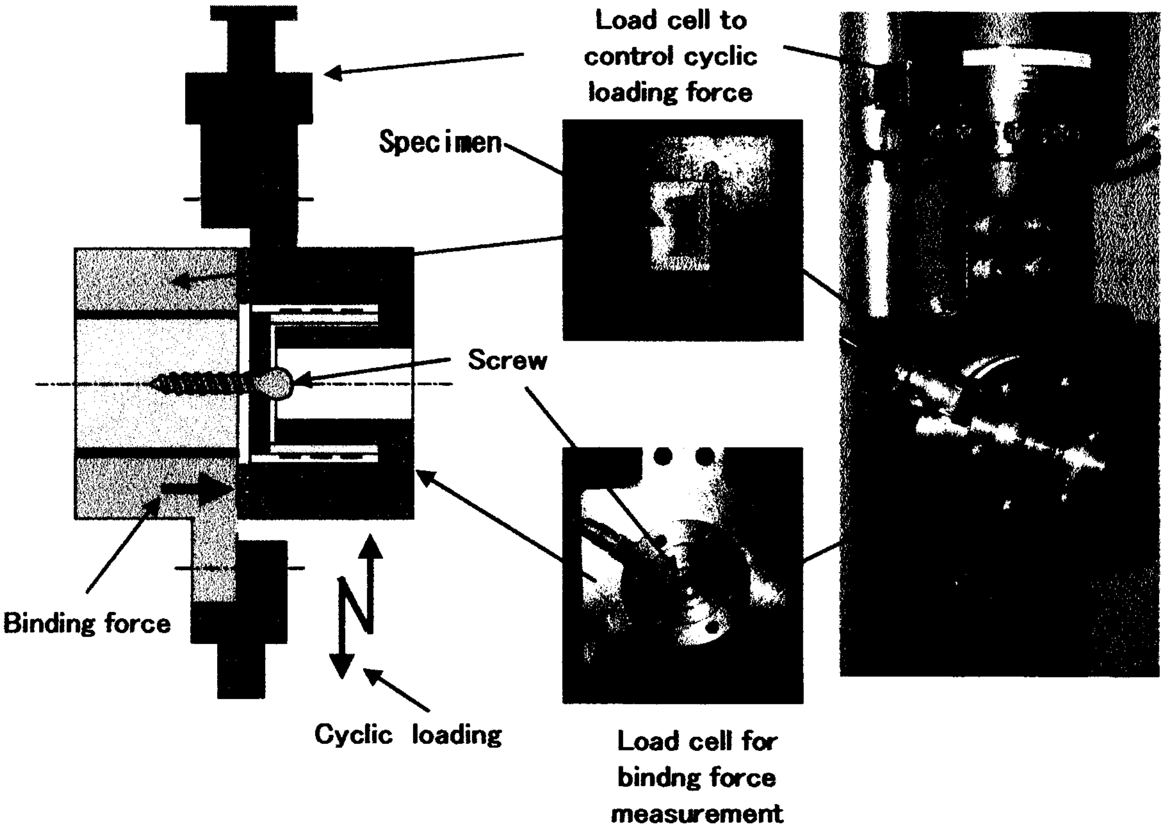
Figure 2: Screw insertion to vertebral bone

The binding force is measured using specially designed load cell of strain gage(Figure 3b). Also the repeated load is applied to vertical to the screw axis until the binding force between plate and vertebra falls to one tenth of initial binding force. The relation of the amplitude of repeated load and the number of cycles was investigated.

Microstructure of bone before and after the test was examined using rconstructed 3D image by a micro CT machine manufactured by Scanco Medical Co., Switzerland. (Figure 4). The solid model FEM (Finite Element Method) analysis of the bone around the screw was done.The used software is ANSYS 5.6 by ANSYS Inc. Pennsylvania, USA



(a) Material testing machine, Survo pulsar EHF-ED5



(b) Binding force measurement

Figure 3: Binding force measurement by material testing machine

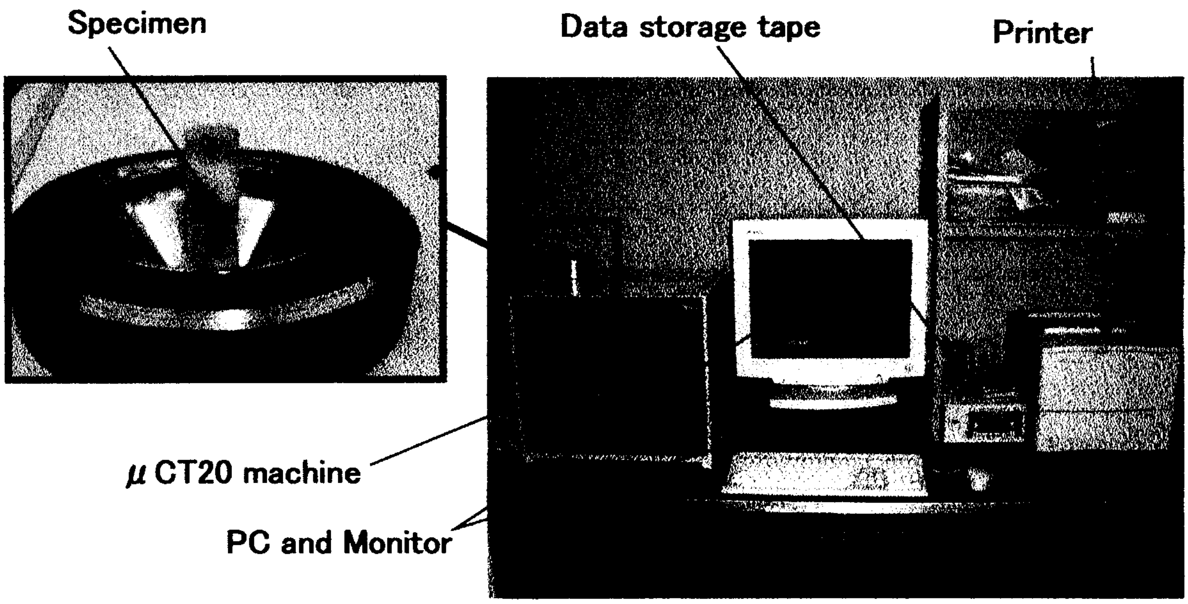


Figure 4: Micro-CT machine, Micro-CT20

RESULT AND DISCUSSION

The obtained binding forces by experiment and by FEM analysis are shown in TABLE 2 and Figure 5. These results show the experiment and FEM analysis have good correlation each other.

Figure 6 is the 3D micro-CT image of bone just after screw hole tapping of pitch 3-mm. The screw insertion test was executed until just after peak-binding force is recorded when the screw insertion was stopped to retrieve the bone for micro-CT observation. Fractured bone region by micro-CT was compared with Von Mieses stress contour by FEM analysis on the screw pitch; 2-mm, 3-mm, 4-mm and 5-mm as shown in Figures 7a, 7b, 7c and 7d respectively and it was found that they have good correlation each other. Then although the structure of cancellous bone is porous and is very complicated, its mechanical property can be understood as a solid material with anisotropy. It was suggested a micro crack initiated in cancellous bone does not affect broader region because it is locally trapped by porous microstructure of the bone.

TABLE 2 Obtained binding forces of pitches from 1 mm to 5 mm by experiment and by FEM analysis.

Pitch (mm)		2	2.5	3	3.5	4	5
Binding force (kN)	**Experiment**	**1.09**	**1.27**	**1.33**	**1.25**	**1.14**	**1.07**
	FEM-analysis	**1.05**	**1.16**	**1.18**	**1.07**	**0.95**	**0.63**

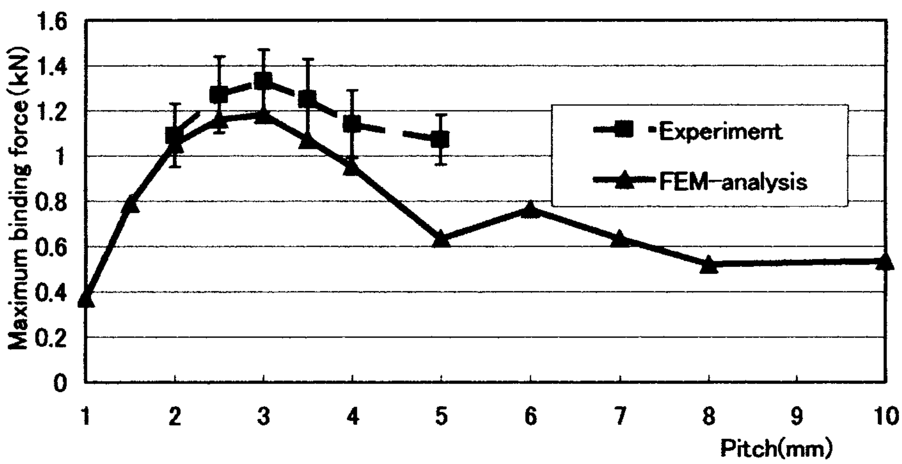


Figure 5 Obtained binding forces of pitches from 1 mm to 10 mm by experiment and by FEM analysis.

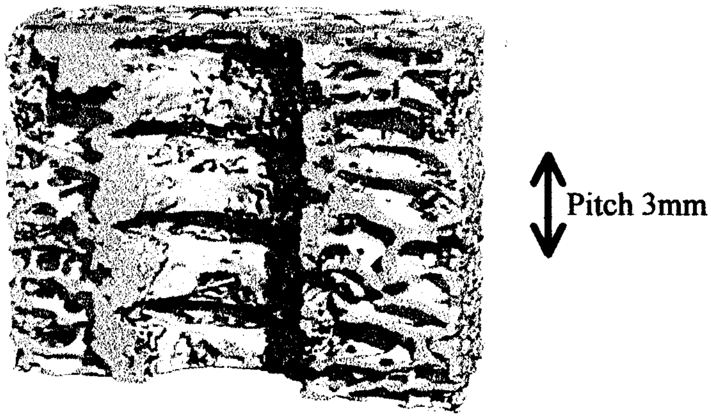
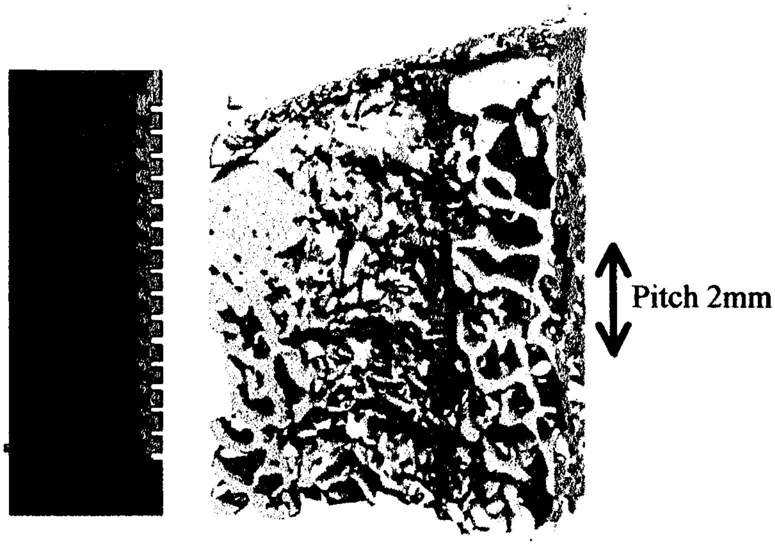
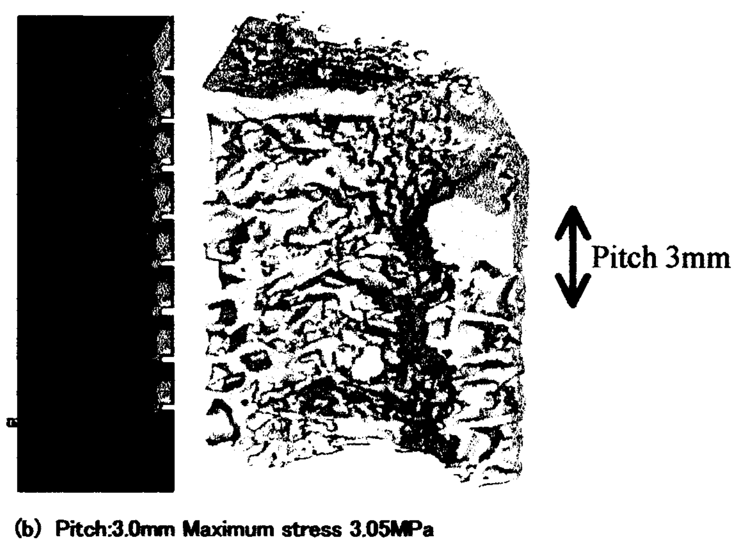


Figure 6: 3D micro-CT image of cancellous bone just after screw hole tapping of pitch 3-mm.

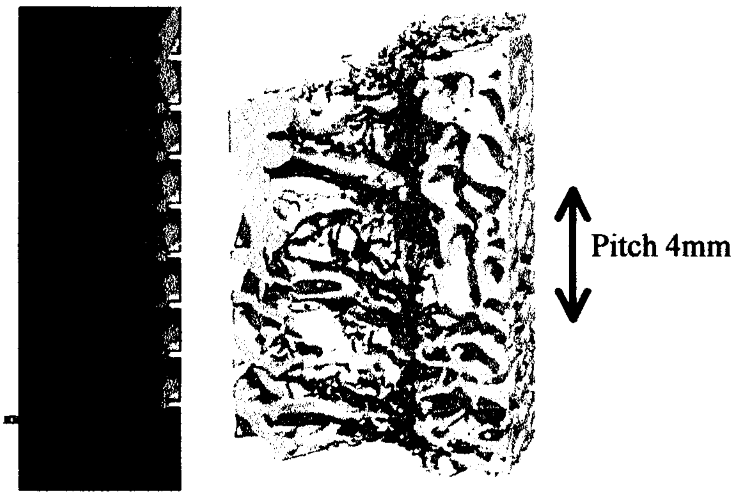


(a) Pitch:2.0mm Maximum stress 3.425MPa

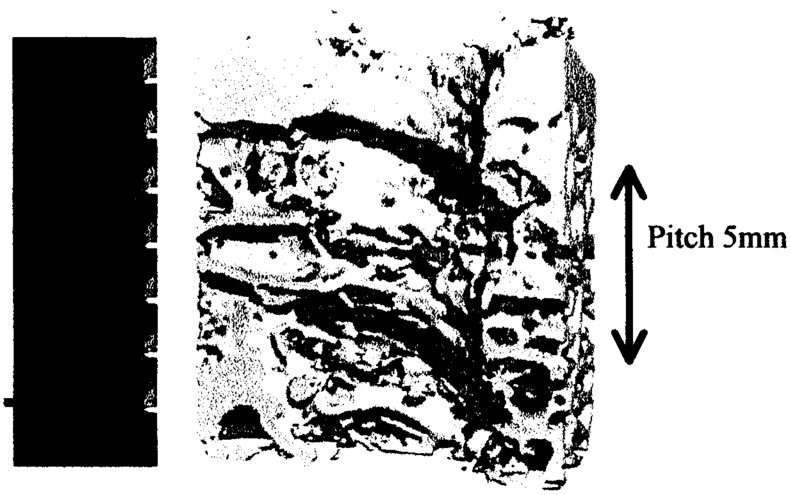


(b) Pitch:3.0mm Maximum stress 3.05MPa

Figure 7ab:The von Mieses stress contour by FE analysis and 3D micro-CT image.
The value shows maximum von Mieses stress



(c) Pitch:4.0mm Maximum stress 3.784MPa



(d) Pitch:5.0mm Maximum stress 5.696MPa

Figure 7cd: The von Mieses stress contour by FE analysis and 3D micro-CT image
The value shows maximum von Mieses stress

CONCLUSION

The result of high stress region of stress distribution by FE analysis was similar to the fractured region by micro-CT image. The mechanical property of cancellous bone can be understood as a solid material with anisotropy and it was suggested a micro crack initiated in cancellous bone does not affect broader region because it is locally trapped by porous microstructure of the bone.

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