Stability of Subchondral Bone Defect Reconstruction at Distal Femur : Comparison Between Polymethylmethacrylate Alone and Steinmann Pin Reinforcement of Polymethylmethacrylate†

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Abstract

Polymethylmethacrylate (PMMA) is often used to fill the large subchondral defects following intralesional curettage of a giant cell tumor of the bone. Many authors have reported the use of Steinmann pins to reinforce the bone cement. However, whether this is of real benefit in improving the stability of the defect is controversial. Thirteen matched pairs of cadaveric distal femurs were obtained and tested in uni-axial compression to determine the strength of this reconstruction. The strength of normal distal femurs was compared with the strength of defective femurs using 5 matched pairs of cadaveric distal femurs. A significant difference between the two groups was demonstrated in the failure load, stiffness, yield point and total energy absorbed to failure ($p < 0.05$). The second part consisted of eight matched pairs of specimens filled with PMMA alone *versus* PMMA with Steinmann pin reinforcement. There was no significant difference in failure load, stiffness, yield point and total energy absorbed to failure ($p > 0.05$). The addition of Steinmann pins did not significantly improve the strength of the subchondral defect reconstruction in uni-axial compression compared with PMMA reconstruction alone.

Key word : Distal Femur, Biomechanical Study, Polymethylmethacrylate, Steinmann Pin

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Giant cell tumor of bone is a locally aggressive primary bone tumor. This tumor accounts for 5 per cent of biopsied primary bone tumors and 20 per cent of benign bone tumors, making it the sixth most common primary osseous tumor[1,2]. More than 75 per cent of giant cell tumors are located near the articular end of a long bone. The most common site involves the distal femur and other common sites include the proximal tibia, distal radius and sacrum. The standard treatment for a lesion that is not involved in articulation is intralesional curettage and packing with bone graft or polymethylmethacrylate (PMMA) [3-6]. In 1987, Johnston recommended using reinforcement bars of heavy threaded Steinmann pins for a large defect[3,7]. He believed that this procedure provided more stability to the bone following this reconstruction. However, the biomechanical benefit of this particular reconstruction is still controversial. The disadvantage of metal pins reinforcing PMMA is that making the early diagnosis of a recurrent giant cell tumor is difficult because of the radiographic artifact created by the Steinmann pins within the cement.

The authors' hypothesis is that Steinmann pin reinforced PMMA and PMMA alone used to reconstruct subchondral lesions of the distal femur with a giant cell tumor do not significantly contribute to the strength of this construction. Nevertheless, there has been no study to compare these two techniques of subchondral bone defect reconstruction in the distal femur. The purpose of this study was to investigate and compare the strength of the two techniques; Steinmann pin reinforced PMMA and PMMA alone, in subchondral bone defects at the distal femur.

MATERIAL AND METHOD

This randomized controlled study consists of two parts. The first part was to compare the strength of normal distal femurs with femurs in which a model defect had been created. The second part studied the difference in strength between the two reconstruction techniques. The sample size of cadaveric distal femurs was calculated from the formula[8]

$$N = \frac{(Z_\alpha + Z_\beta)^2 S^2}{D^2}$$

S (Standard deviation of difference from the pilot study of 3 pairs of distal femur) = 78 N

D (Difference desired to detect) = 100 N (clinical observation from toe-touch partial weight bearing)

The first part used a confidence interval of 95 per cent ($\alpha = 0.05$) and power of 80 per cent ($\beta = 0.20$). The sample size for this study was 4.775 or 5 pairs. The second part used a confidence interval of 95 per cent ($\alpha = 0.05$) and power of 95 per cent ($\beta = 0.05$). The sample size needed for the second part was 7.906 or 8 pairs. Of the 13 cadaveric distal femurs used in this study, 11 pairs were from males and 2 pairs from females. The mean age of the cadavers was 27 years (range from 20-40 years). The cadavers had no medical disease that affected the quality of the bones tested.

A defect was created in all the femur specimens except for five controls. The defect involved the majority of the antero-medial cortex of the distal femoral metaphysis. The cancellous bone of the medial metaphysis and epiphysis was removed to create a defect extending to the subchondral bone of the medial femoral condyle by using a high-speed burr and curette. The round-shaped defect measured 4 by 4 cm in diameter and 3 cm in depth in both its superoinferior and medio-lateral planes. (Fig. 1) This medial femoral condyle defect simulated the defect created by curettage of a giant cell tumor. This study chose a medial femoral condyle defect because many studies have found that the medial femoral condyle bears a major portion of load during gait[9-11].

The 8 paired specimens used in the second part of the study were randomized *via* a simple manner. In specimens with an even number, the defect was filled with PMMA (Surgical Simplex P, Howmedica, Inc, Co. Clare, Ireland) alone. The odd number specimens were filled with PMMA reinforced with 3 pieces of threaded Steinmann pins (size 3.6) (Zimmer, Inc, Co, Warsaw, Indiana). Each piece of Steinmann pin was accurately measured to fit snugly in the defect in a divergent manner with the apex located at the proximal part of the defect (Fig. 2).

After filling the defect with PMMA and waiting until the cement settled, all the specimens were checked by radiographs in both antero-posterior and lateral views to confirm the containment and

alignment of both PMMA and Steinmann pins. All the specimens in both studies were placed on a cement block and mounted parallel to the universal testing machine (Shimadzu: AG 2000B). Then a uni-axial compression test was performed on the medial femoral condyle by the indentor (size 2.5 by 5 cm) at a rate of 2 mm per second until the femur failed (Fig. 3). The authors recorded the data of the failure load, stiffness, yield point, and total energy absorbed to failure in the case record form. The data was analyzed statistically by using a paired *t*-test.

RESULTS

From the first part of the study, the 5 defective distal femurs demonstrated significantly lower values than the intact control group in terms of the failure load (defect 5,274 ± 1,432 Newton, intact 9,542 ± 2,063 Newton, p = 0.003), stiffness (defect 1,785 ± 344 Newton/mm, intact 3,001 ± 1,060 Newton/mm, p = 0.04), yield point (defect 4,720 ± 1,230 Newton, intact 8,840 ± 1,941 Newton, p = 0.004) and total energy absorbed to failure (defect 10,071 ± 3,770 Newton/mm, intact 23,836 ± 6,880 Newton/mm, p = 0.002).

However, the defects in the distal femurs filled with PMMA alone in the second part of the study were not significantly stronger than the ones that were reinforced with Steinmann pins in terms of failure load (PMMA alone 7,686 ± 1,111 Newton, PMMA with pins 7,083 ± 982 Newton, p = 0.196), stiffness (PMMA alone 2,338 ± 285 Newton/mm, PMMA with pins 2,065 ± 207 Newton/mm, p = 0.091) and yield point (PMMA alone 7,312 ± 1,118 Newton, PMMA with pins 6,756 ± 1,007 Newton, p = 0.201). For the total energy absorbed to failure, the values obtained in specimens filled with PMMA alone were not significantly lower than those obtained in the distal femurs reinforced with Steinmann pins (PMMA alone 22,282 ± 5,514 Newton/mm, PMMA with pins 22,895 ± 4,613 Newton/mm, p = 0.689) (Fig. 4A-D).

All the fractures in the specimens in the second part of the study were found at the subchondral or metaphyseal part of the bones, there were no fractures on the cement composites.

DISCUSSION

Sir John Charnley first reported the application of bone cement in orthopaedic surgery for the fixation of prosthetic devices[12]. Recently bone cement has not only been used in the field of arthroplasty, but PMMA has been used in orthopeadic oncology for the purpose of filling bone defects and giving

Fig. 1. A specimen of the distal femur showing the defect at the medial condyle.

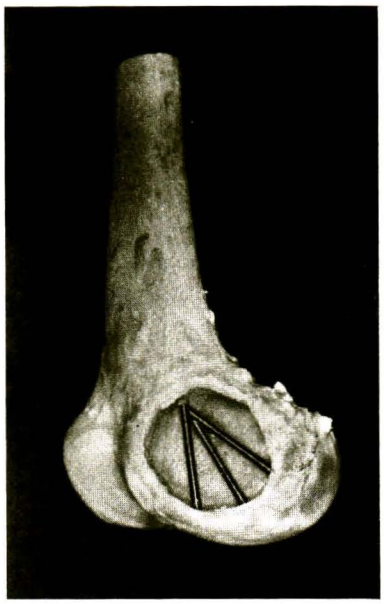

Fig. 2. A specimen showing how the 3 pieces of threaded Steinmann pin fit into the defect before filling with PMMA.

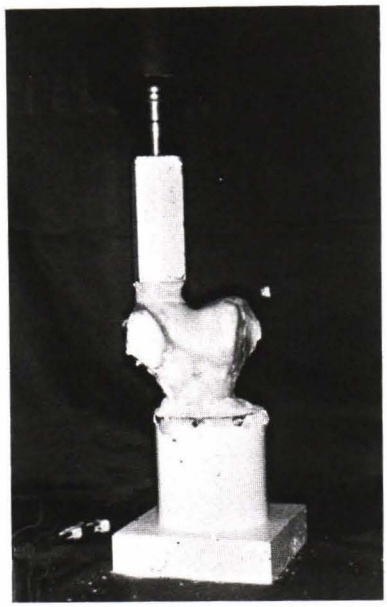

Fig. 3. The specimen was placed on a cement block and compression was applied to the medial femoral condyle by the indentor.

stability to the bone especially in giant cell tumors of bone[13]. PMMA has the advantage of restoring stability immediately, thus allowing the patient to move the joint early on and also bear weight on a weight-bearing joint. Many series have reported that using PMMA to fill the defect following curettage of a giant cell tumor of bone had a lower rate of local recurrence[5,7,14,15]. PMMA was used as adjuvant material to decrease the rate of local recurrence due to the exothermic heat reaction of polymerization or direct toxic effect. Cases with tumor recurrence, can be easily demonstrated by a lytic lesion at the junction of the bone and cement on a plain radiograph[16].

Many techniques of applying PMMA to the defect following curettage of a giant cell tumor of bone have been suggested by different authors. Persson and Wouters described using PMMA alone[15]. Johnston and DeComago reported using threaded Steinmann pins and polyethylene reinforcement with cement to give more support to the subchondral region that has been curettaged[3,7,17]. However, in patient with tumor recurrence that need to be confirmed by compu-

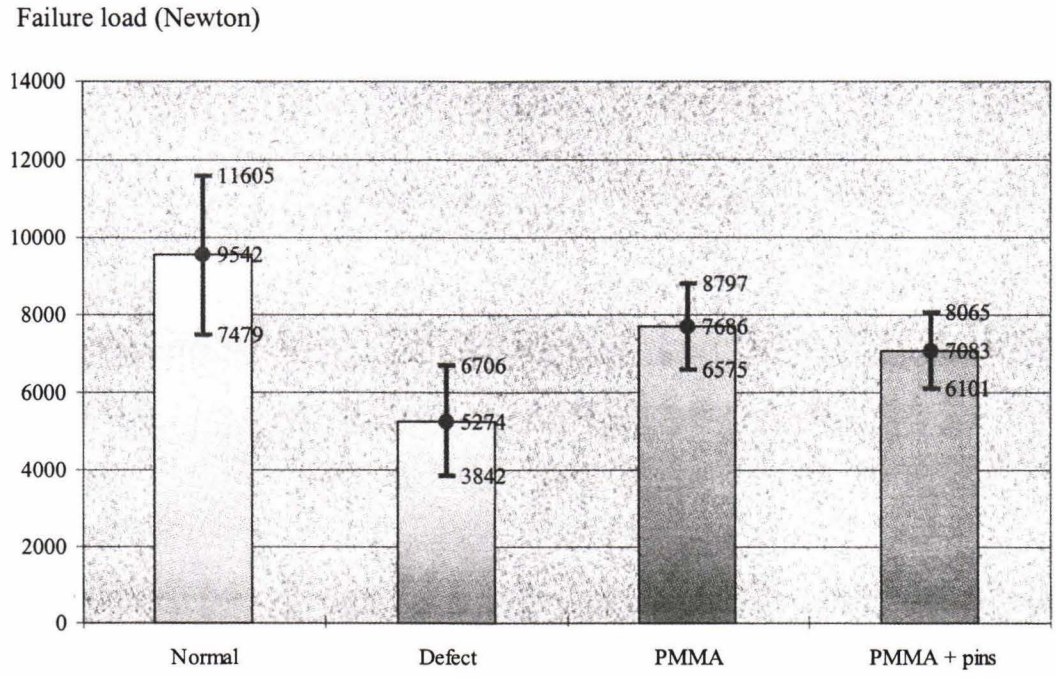

Fig. 4A. Failure load of all model specimens. There was no significant difference between the specimens reconstructed with PMMA alone or PMMA reinforced with pins.

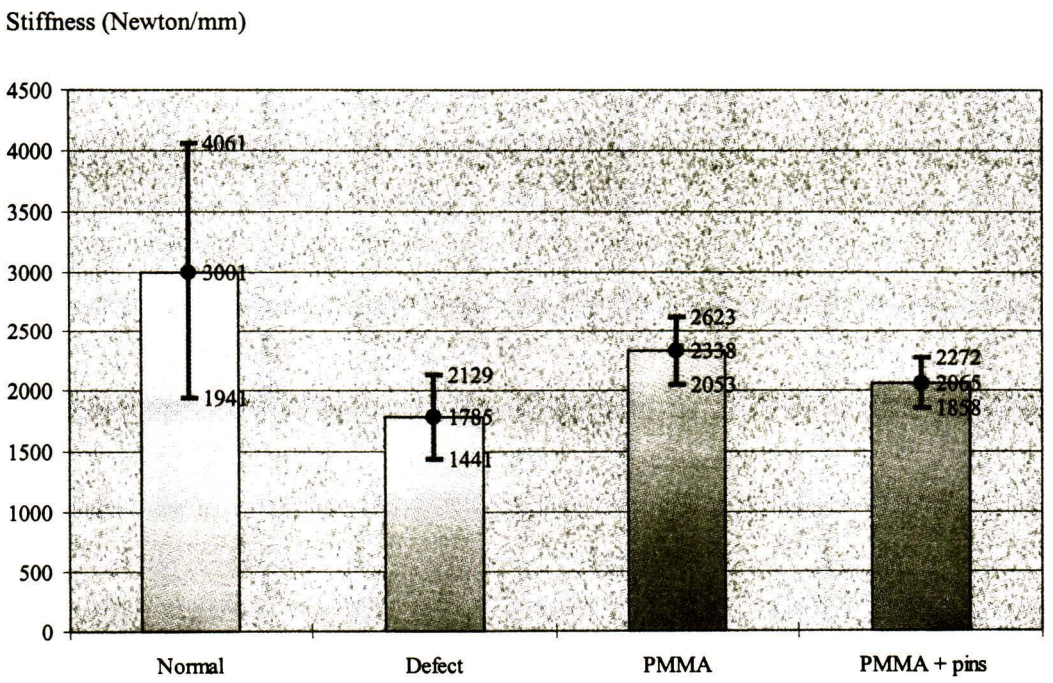

Fig. 4B. The result of stiffness value, no significant difference was demonstrated between either reconstructions.

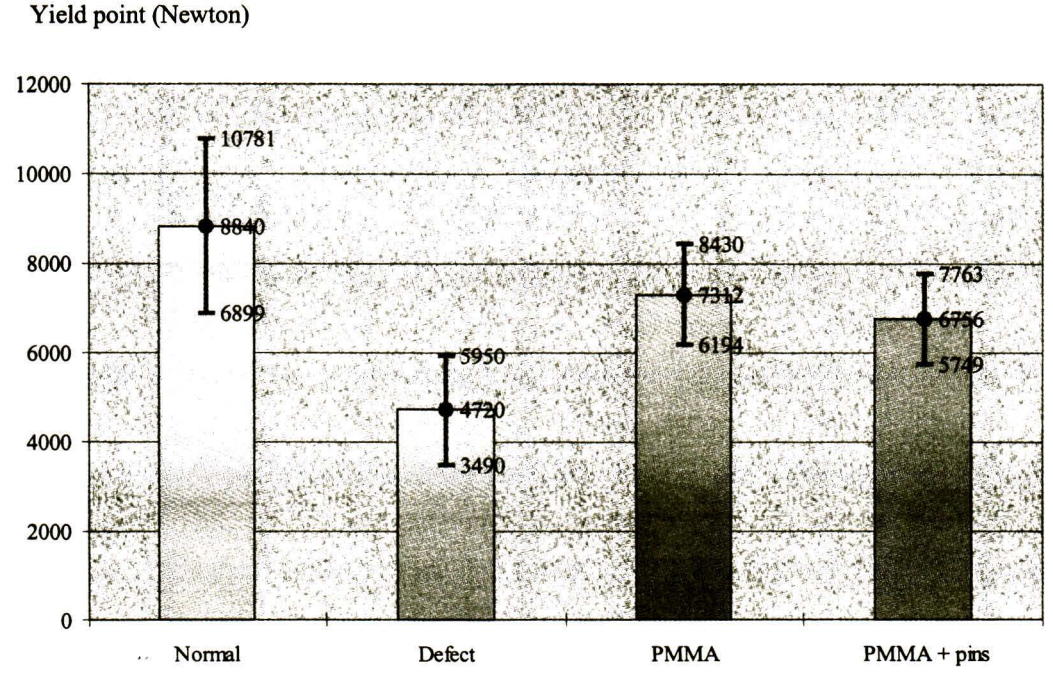

Fig. 4C. Yield point of all specimens. There was no significant difference between the specimens reconstructed with PMMA alone or PMMA reinforced with pins.

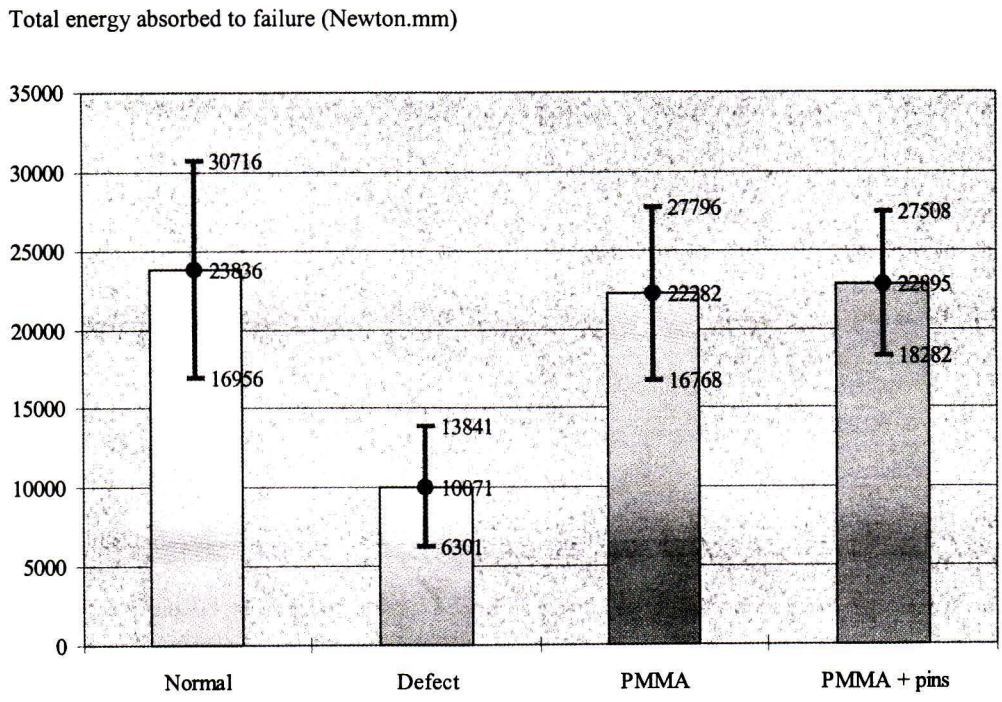

Fig. 4D. Total energy absorbed to failure values of all specimens. There was no significant difference between either reconstructions.

terized tomography (CT) scan or magnetic resonance imaging (MRI). The reinforced metals might make the detection of tumor recurrence difficult because the radiographic artifact from CT scan or MRI can obscure the lesion. The technique of Steinmann pin reinforcement is also more time consuming and expensive than reconstruction with PMMA alone.

The first part of this study confirmed that the model defects had statistically significant lower values than the control group in terms of failure load ($p = 0.003$), stiffness ($p = 0.04$), yield point ($p = 0.004$) and total energy absorbed to failure ($p = 0.002$) in the uni-axial compression test. The presented model was similar to that when a giant cell tumor of bone of the condyle and the subchondral bone of the distal femur is curettaged. This defect model was thus standard and was used to compare the strength of each reconstruction in the second part of the study.

In the second part of the study, the authors found that the strength of the defects reconstructed with PMMA alone was not significantly different from the specimens reconstructed with Steinmann pin reinforced PMMA in terms of failure load ($p = 0.196$), stiffness ($p = 0.091$), yield point ($p = 0.201$) and total energy absorbed to failure ($p = 0.689$). The present study produced similar results to Patterson et al who performed a biomechanical study to compare the use of PMMA alone and Steinmann pin reinforced PMMA in filling subchondral bone lesions of cadaveric proximal medial tibia. They found no significant difference in mean failure load, stiffness, yield point and total energy absorbed to failure[18]. The authors believe that Steinmann pin reinforced PMMA might increase the strength of the composite structure compared with PMMA alone. However, there was no significant difference in transferring the stress pass through the surrounding bone. Evidence of fracture of the specimens occurred only in subchondral and metaphyseal bone. There were no fractures of the cement composites.

In contrast, the study of Leeson et al investigated the changes in surface strain which occurred in the distal femur following bone curettage, and examined the effectiveness of using PMMA cement augmented by Steinmann pins in reducing the strain. They found that two Steinmann pins significantly reduced the strain in the distal femur to near normal values and should be used to augment the PMMA in

filling the defect. This reconstruction provided significantly added support for load transference across the defect[19].

This study was tested only in uni-axial compression and did not include other axial testing such as bending or torsion. A further biomechanical study to investigate other axial planes will confirm or refute the necessity for Steinmann pin reinforcement and the benefits in treating patients with giant cell tumors of the bone in this manner.

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การทดสอบทางชีวกลศาสตร์เปรียบเทียบความแข็งแรงของโพรงกระดูกต้นขาส่วนปลายระหว่างการใช้ซีเมนต์กระดูกอย่างเดียวและเสริมด้วยโลหะชนิดหมุดสไตน์มานน์

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การใช้ซีเมนต์กระดูกเพื่อทดแทนและเสริมความแข็งแรงของโพรงกระดูกที่เกิดภายหลังการผ่าตัดขูดเนื้องอกกระดูกชนิด giant cell tumor เป็นที่นิยมในปัจจุบัน อย่างไรก็ตามยังมีข้อถกเถียงถึงความจำเป็นที่ต้องเสริมความแข็งแรงของซีเมนต์กระดูกด้วยโลหะชนิด Steinmann pins คณะผู้วิจัยได้ทำการทดลองศึกษาเปรียบเทียบความแข็งแรงทางชีวกลศาสตร์ของกระดูกส่วนปลายบริเวณกระดูกต้นขาที่ได้รับการขูดเป็นโพรงจำนวน 13 คู่ โดยใช้ universal testing machine และแท่งโลหะที่ออกแบบให้เข้ากับกระดูก เพื่อจับให้อยู่ในแนวตั้งตรงและทดสอบแรงกดในแนวดิ่งตามแนวแกน บันทึกแรงสูงสุดที่ทำให้กระดูกหัก ตำแหน่งและลักษณะของการหัก จากการศึกษาครั้งนี้แสดงให้เห็นว่าความแข็งแรงของโพรงกระดูกต้นขาส่วนปลาย ที่ได้รับการเสริมด้วยซีเมนต์กระดูกและ Steinmann pins ไม่มีความแตกต่างอย่างมีนัยสำคัญทางสถิติทั้งในส่วนของ failure load, stiffness, yield point และ total energy absorbed to failure เมื่อเปรียบเทียบกับโพรงกระดูกที่ได้รับการเสริมด้วยซีเมนต์กระดูกเพียงอย่างเดียว ดังนั้นจึงไม่มีความจำเป็นในการเสริมความแข็งแรงซีเมนต์กระดูกด้วยโลหะชนิด Steinmann pins ภายหลังขูดเนื้องอกจากกระดูก รวมทั้งการใช้โลหะชนิดนี้มีผลเสียต่อการใช้ภาพถ่ายรังสีคอมพิวเตอร์ติดตามการเกิดซ้ำใหม่ของเนื้องอกกระดูกได้

คำสำคัญ : กระดูกต้นขาส่วนปลาย, การทดสอบทางชีวกลศาสตร์, ซีเมนต์กระดูก, Steinmann Pins

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