Journal of Orthopaedics 14 (2017) 495–500

Contents lists available at ScienceDirect

Journal of Orthopaedics

journal homepage: www.elsevier.com/locate/jor

Original Article

Strain measurements of the tibial insert of a knee prosthesis using a knee motion simulator

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ARTICLE INFO

Article history:
Received 15 June 2017
Accepted 6 August 2017
Available online 9 August 2017

Keywords:
Total knee arthroplasty
Knee motion simulator
Principal strain
Varus-valgus
Wear

ABSTRACT

Objective: The longevity of a knee prosthesis is influenced by the wear of the tibial insert due to its posture and movement. In this study, we assumed that the strain on the tibial insert is one of the main reasons for its wear and investigated the influence of the knee varus-valgus angles on the mechanical stress of the tibial insert.
Methods: Knee prosthesis motion was simulated using a knee motion simulator based on a parallel-link six degrees-of-freedom actuator and the principal strain and pressure distribution of the tibial insert were measured. In particular, the early stance phase obtained from *in vivo* X-ray images was examined because the knee is applied to the largest load during extension/flexion movement. The knee varus-valgus angles were 0° (neutral alignment), 3°, and 5° malalignment.
Results: Under a neutral orientation, the pressure was higher at the middle and posterior condyles. The first and second principal strains were larger at the high and low pressure areas, respectively. Even for a 3° malalignment, the load was concentrated at one condyle and the positive first principal strain increased dramatically at the high pressure area. The negative second principal strain was large at the low pressure area on the other condyle. The maximum equivalent strain was 1.3–2.1 times larger at the high pressure area. For a 5° malalignment, the maximum equivalent strain increased slightly.
Conclusion: These strain and pressure measurements can provide the mechanical stress of the tibial insert in detail for determining the longevity of an artificial knee joint.

1. Introduction

Total Knee Arthroplasty (TKA) is a successful surgical treatment with knee prostheses and can relieve pain and enable recovery from knee deformability for severe knee injury patients such as those suffering from osteoarthritis and rheumatoid arthritis. A greater than 90% implant survival rate at 10 to 15 years has been reported. Unfortunately, a significant number of failures occur due to the severe *in vivo* mechanical environment, thus requiring revision surgeries.[1] The alignment of the knee prosthesis during replacement surgery can affect its long-term lifetime. A knee prosthesis consists of a femoral component, tibial component, and polyethylene tibial insert. Malalignment of the tibial component alters the distribution of tibial loading, resulting in increased shear forces and wear at the tibiofemoral interface. According to clinical reports, a tibial malalignment of >3° varus increases the risk of medial bone collapse[2] and causes an 11 times higher failure rate in TKAs with varus tibial malalignment.[3] Furthermore, an increase of 1.2 times in the wear of implants mounted with a >3° varus malalignment has been reported using an *ex vivo* knee wear simulator.[4] Therefore, the tibial component should be placed in neutral alignment.[5] The femoral component has the medial and

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http://dx.doi.org/10.1016/j.jor.2017.08.003

lateral condyles, and the load is balanced between the two condyles during a normal gait cycle. However, with as little as a 3° variation in alignment, the pressure distribution and total load in both condyles changes significantly.[6] In particular, the tibial forces may determine the wear of polyethylene, the stress distribution in the implant, and the stress transfer to bone. Previously, the tibial forces were measured using a strain gage embedded in the stem of a tibial component with a knee simulator[7] and *in vivo*.[8,9] However, the stress of the surface between the polyethylene tibial insert and the femoral component should be more important when considering the wear of polyethylene.

In this study, we focused on the strain as one of the main reasons for the wear of polyethylene and investigated the mechanical stress of the tibial inset at a neutral alignment and during varus-valgus malalignment. In the experiment, a mobile-bearing knee prosthesis was mounted on a knee motion simulator

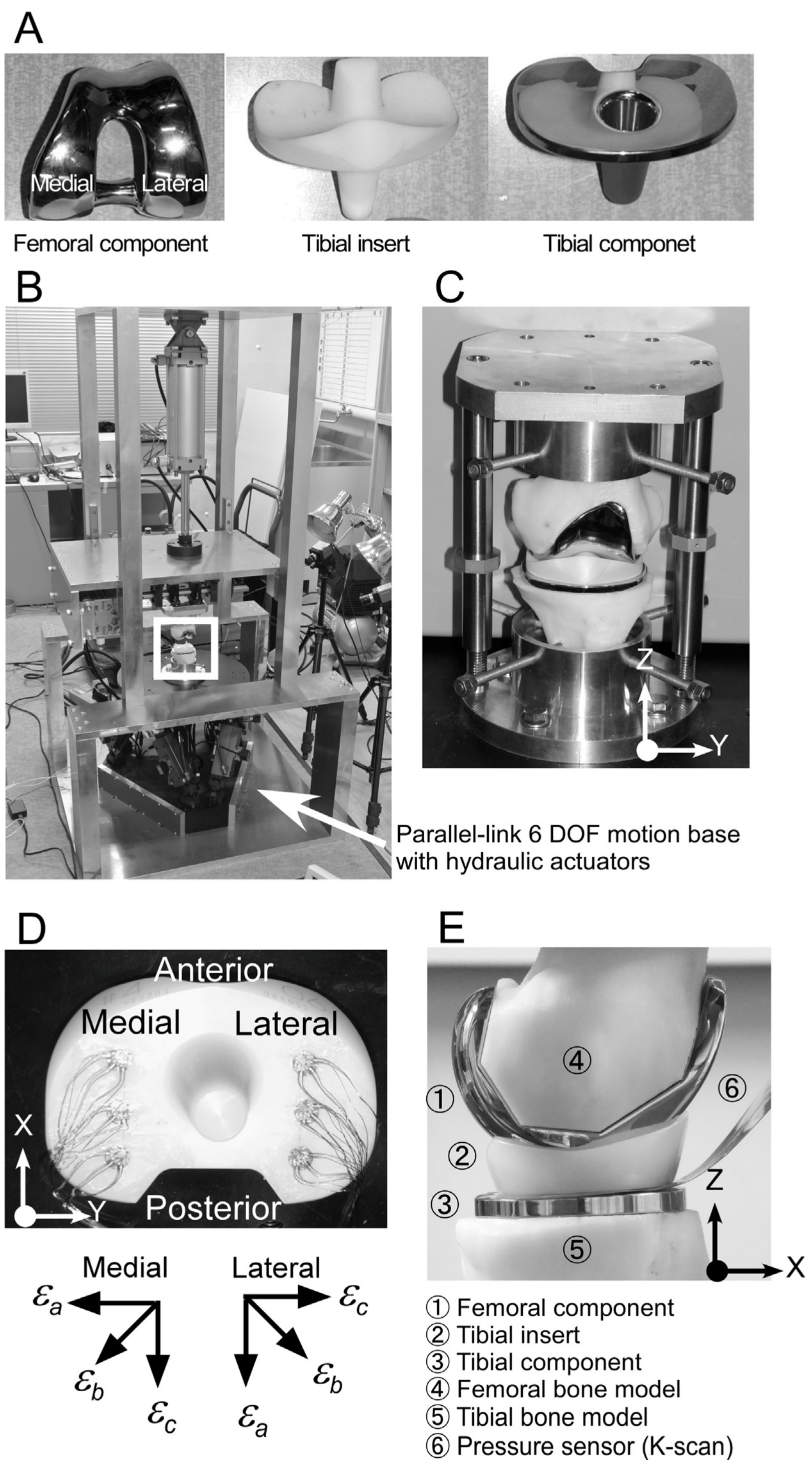

Fig. 1. Artificial knee joint simulator. (A; mobile-bearing left knee prosthesis, B: Schema, C: Artificial knee joint, D: 3-axis strain gages on the back side of the tibial insert, E: Artificial knee joint with a pressure sensor between the tibial component and the tibial insert.)