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REVIEW ARTICLE

Three-dimensional motion analysis and its application in total knee arthroplasty: what we know, and what we should analyze

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Abstract
Introduction This paper will review three-dimensional (3D) motion analysis studies done in my laboratory to present an overview of what we have found.
Materials and methods We have looked at parameters such as roll-back, rotation, the pivot center of rotation etc. using a 2D–3D registration technique by evaluating knees before and after implantation of a total knee arthroplasty.
Conclusion This technique allows comparison of preoperative motion to that after total knee surgery. We have found the phenomenon of "reverse screw-home" to be a common motion pattern in osteoarthritis and it is often present after implantation of a total knee prosthesis.

Introduction

The Total Condylar Prosthesis is a semi-constrained total knee that, after many designs were attempted, primarily in the United States, was accepted as the preferable design at the end of the 1970s. Problems such as infection, loosening, polyethylene wear (possibly because of malposition of implant components) were gradually solved with techniques such as computer navigation. Studies demonstrating 90 % survival after 20 years have indicated [1] that position is not as dependent on post-operative position as previously thought. Clinical research has focused more recently on patient satisfaction and our belief is that restoring more normal kinematics will lead to better patient satisfaction [2].

This paper will detail the author's biomechanics studies and clinical results using three-dimensional (3D) motion analysis and will suggest the direction for future research.

3D motion analysis, methods and parameter evaluation

Roentgen stereophotogrammetric analysis (RSA) has been used to determine 3D motion paths of knees after total knee arthroplasty (TKA). This system allows determination of motions in 6 degrees of freedom (6DOF) as suggested by Grood [3]. Although this provides excellent quantitative descriptions, some issues are not easily understood. To understand total knee motion, femoral roll-back (FRB) and screw-home motion (SHM — a typical normal motion in which the tibia rotates externally during knee extension with the amount, direction and pivot center being targets of analysis) need to be determined. Studies using RSA determined that after TKA, SHM and FRB were similar but diminished [4]. RSA is a quasi-dynamic method in which motion must be stopped to obtain images: thus the effects of uninterrupted motion cannot be captured. With an electric goniometer or magnetic tracker, two-dimensional (2D)–3D image registration of motion capture systems can provide uninterrupted motion.

3D knee motion analysis by 6DOF goniometer

The electric 6DOF goniometer was attached to the patient's thigh with a strap. The goniometer is calibrated by biplanar X-ray to an anatomic coordinate system with the knee in full extension, thus defining the motion to the anatomy of the knee (Fig. 1). Using this method, SHM was clearly

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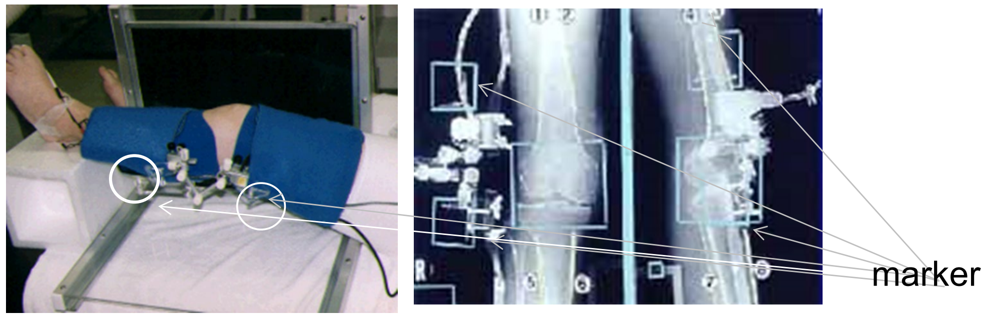

Fig. 1 3D motion analysis system with 6DOF electric goniometer — the data transformed by biplanar X–ray method

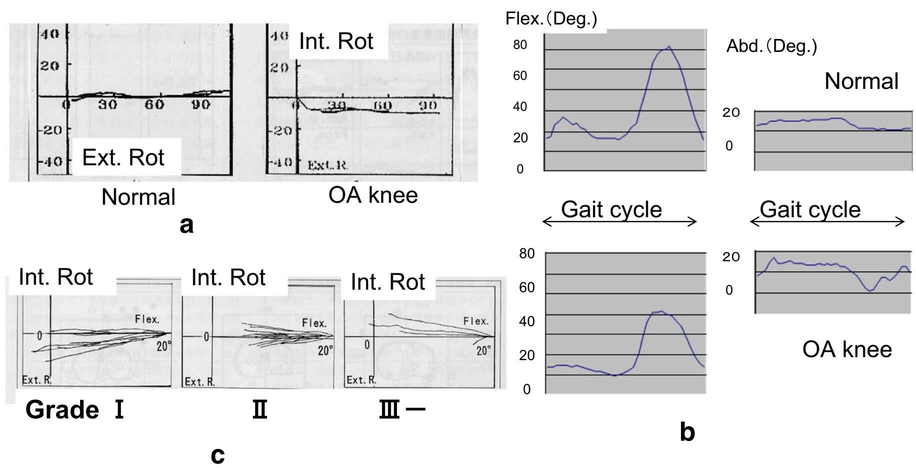

Fig. 2 Results of 3D motion analysis of OA knee. **a** Screw-home motion clearly detected in normal subjects. **b** Using gait analysis of OA patients, lateral thrust was detected as an acute adduction with decreased double knee flexion. **c** Screw-home motion was diminished by the progression of OA

detected as external rotation of the tibia near full extension, and the amount of this motion was diminished with osteoarthritis (OA). Using gait analysis, a lateral thrust (also known as varus thrust) was detected at the early phase of stance and double knee action was diminished, more so with progression of OA (Fig. 2). At early stance phase in severe OA in preoperative patients before TKA, the motion was mainly external rotation which was a reverse of SHM during knee flexion but the rate of external rotation was decreased, resulting in no rotation proportional to the area of cartilage destruction determined from the tibia resected at the TKA surgery [5] (Fig. 3). We reported motion analysis after TKA and showed: (1) diminished double knee action in gait, (2) anterior translation during knee flexion observed in posterior cruciate ligament (PCL) sacrificing prosthesis, and (3) SHM was small and some showed reverse SHM. Further, the amount of rotation either SHM or reverse SHM at terminal extension was different based on the type of prosthesis used in the TKA [6]. SHM is an average of 10.6° external rotation, and was determined with acceptable accuracy [7].

Clinical results and motion analysis of high tibial osteotomy were compared before and after osteotomy [8]. Preoperatively, most of the patients showed lateral thrust, which

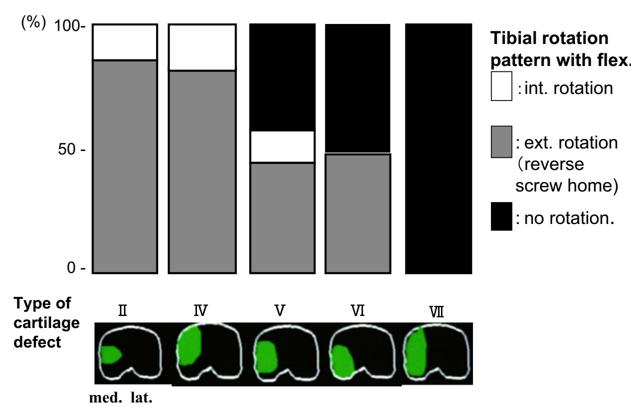

Fig. 3 Relation between the knee motion (rotation) and defects of tibial articular surfaces of TKA patients, preoperatively

disappeared in most patients after osteotomy. Consequently, a few patients showed SHM, but after osteotomy none showed SHM and some patients tended to have reverse SHM. Therefore, we concluded that the thrust is mainly related to change of the weight-bearing axis, but rotation seemed to be more related to joint congruity which was not changed by osteotomy, and this was aggravated by time.