대퇴경골부 회전중심각 최적화를 위한 Knee Brace Hinge의 개발

Development of Knee Brace Hinge for the Optimization of Rotation Center in Femoro-tibio Joint

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1. Introduction

The knee joint has a more complicated geometry and biomechanics of movements than the hip joint. The incidence of knee injuries and degeneration is higher than most other joints. Similar to most other joint replacements, the knee joint replacement development has been an evolutionary process, relying on intuitive design, empirical data, and laboratory studies. It has long been popular to describe tibio-femoral kinematics in terms of the relative motions of the two bones: the femur moving bodily posteriorly on the tibia as the knee flexes so-called femoral ‘roll-back’. Furthermore, it would enlarge the lever-arm of the extensor mechanism so increasing mechanical advantage in extending the flexed knee. In conveying the concept of ‘rollback’, distinction between motion of tibia and femur and the change in position of their articular contact points are rarely made clear. Tibio-femoral kinematics has been thought to be largely driven by tension in the cruciate ligaments. Williams *et. al*.[1] was the first to describe the concept of the tibia, femur and cruciate ligaments functioning as a rigid four-bar mechanical linkage to produce ‘roll-back’. The ‘four-bar link’/‘rollback’ model is based on findings of studies of cadaveric specimens, two-dimensional radiographs, and computer based mathematical models[2,3,4]. In reality the cruciate ligament arrangement is multiplanar. Whilst the posterior cruciate ligament (PCL) lies largely in the sagittal plane, the anterior cruciate ligament (ACL) is truly triplanar in orientation. Furthermore, the PCL appears curved on standard MRI scans undertaken with the knee close to straight and so to a large extent is far from rigid. In sagittal section medially the convex femur articulates with a concave tibia whereas laterally two convex surfaces exist (see Fig. 1 from Andy Willians *et. al.* "Understanding Tibio-Femoral Motion"[1]). In the four-bar model there is also no allowance for longitudinal (axial) rotation, which plainly can occur at the knee. Rest orthosis are created by a stiff composite, by either casting or a line. Knee sleeves are elastic non-adhesive orthosis associated with various devices aimed at patellar alignment or frontal femoro-tibial stabilization.

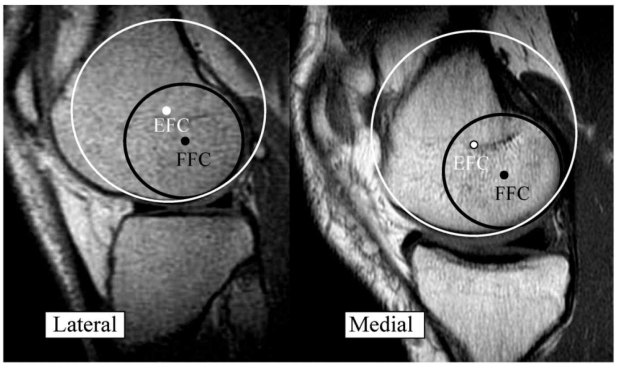

Fig. 1 Sagittal MRI images of the lateral and medial tibiofemoral joints showing the posterior (Flexion Facet Centers-FFC) and anterior (Extension Facet Centers-EFC) circular arcs of the femoral condyles[1]

2. Development of Knee Movement using the Reciprocator

Unloading knee braces are, like knee sleeves, functional devices. They are composed of external stems, hinges and straps. Their purpose is to decrease compressive loads transmitted to the joint surfaces, either in the medial or lateral femoro-tibial compartment, depending on the valgus or varus position of device. Although functional knee braces are generally not believed to mechanically stabilize the knee joint, there continues to be support for the idea that these braces may evoke motor pattern changes that offer protection to the ACL and allow for better bilateral kinetic symmetry during gait. Similar research in healthy participants has shown that the use of a functional knee brace may be one factor that explains the emergence of gait adaptations observed in ACL-deficient individuals. Under the newer paradigm of motor pattern alteration rather than mechanical stabilization, it was of great interest to determine the effect of brace type, hinge misalignment and the influence of both variables on the net joint moment patterns of the lower limb(See Fig. 2). In contrast to the functional active arc there is profound asymmetry between the shapes of the medial and femoral condyles articulating with the tibia. The medial femoral condyle articulates with the upwardly sloping anterior tibial surface. As the lateral femoral condyle rotates internally when it moves forward in extension, it rolls down over the anterior edge of the lateral tibial plateau to compress the anterior horn of the lateral meniscus hence presumably the presence of a recess in the lateral tibial plateau and the sulcus terminalis of the lateral femoral condyle. This arc from approximately 20° to 120° of flexion is influenced by neuromuscular control. During this phase longitudinal rotation with flexion is not obligatory and can to a large extent be

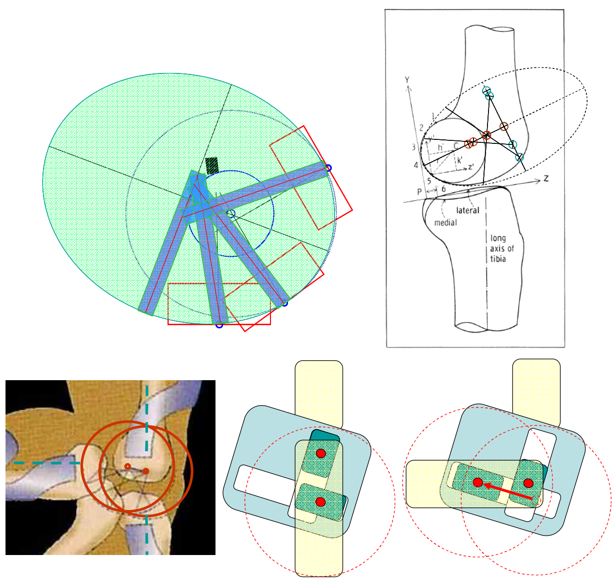

Fig. 2 Reciprocal movement joint of the knee and their application by principle of reciprocator

Table 1 Mechanical properties of knee brace CFRP parts (Toray T300)

Designation	Number of filament	Tensile strength (MPa) / (kg_f/mm^2)	Tensile Modulus (GPa) /(kg_f/mm^2)	Elongation (%)	Density (g/cm^3)
T300 -300	3,000	3,530 / 360	230 / 23,500	1.5	1.76

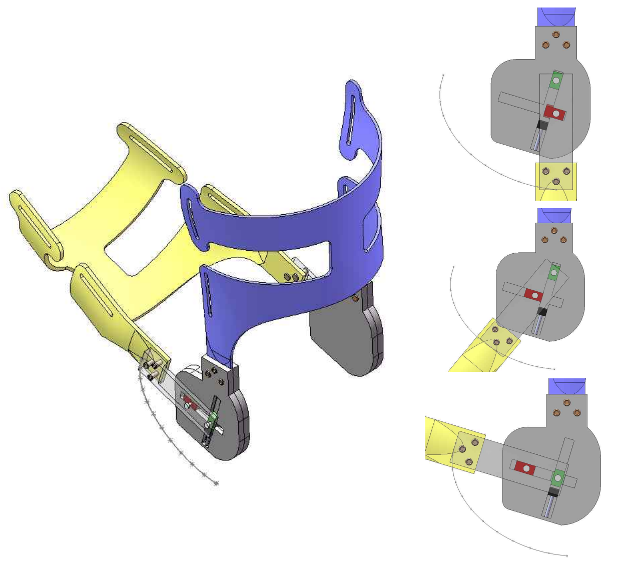

Fig. 3 Reciprocator type osteoarthritis knee brace using CFRP laminates made by our research group

reversed by voluntarily rotating the tibia externally during flexion allowing the knee to function almost as a uniaxial hinge. The mechanisms responsible for axial rotation with flexion are not defined and do not appear to be simply under the control of the cruciate ligaments as was previously thought. In this arc from 120° to 140° of flexion tibio-femoral motion is passive resulting from external force to allow extra flexion (See Fig. 3). Medially the femoral condyle rises up approximately 2mm as it moves posteriorly riding up on the posterior horn of the medial meniscus. If the sagittal profiles of the femoral condyles were single radius curves or J-shaped (closing helix) type of curves, and the tibial surfaces flat, this would have to be true. The situation for a circle would be analogous to the wheel of a car moving on the road: whether sliding or rolling, the contact point would lie on a line perpendicular to the road passing through the centre of the wheel. Hence as the wheel moved so, correspondingly, would the contact point. Laterally the tibia presents a broadly convex surface to the femur. The medial femoral condyle surface describes arcs of two circles. The more anterior (the 'extension' facet) is shorter and has a larger radius, than the posterior (the 'flexion facet'). In the lateral joint compartment, the femoral surface moves posteriorly by a combination of rolling and sliding, and akin to a wheel takes the articular contact point back with it. Medially the joint surface motion is almost exclusively by sliding, initially in the early part of flexion, about the center of the more anterior 'extension facet center' and then from approximately 30° to 40° about the centre of the more posterior arc. This shift is accompanied by a corresponding posterior change in position of joint surface contact, but not a posterior bodily transition of the femur. In early flexion to 30° or 40° in the medial compartment contact is between the extension facet of the femoral condyle and anterior tibial 'upslope'. In deeper flexion contact is between the femoral flexion facet and the more posterior flat medial tibial surface.

3. Conclusions and Future Development

The history of knee replacement shows improvements in implant performance were associated with the designs becoming closer in shape to the natural knee. Current designs have produced very successful functional outcomes from 0° to 90° of flexion. Most are designed to produce femoral 'roll-back' either by preserving the PCL or substituting it for the cam-post mechanisms familiar to the posterior stabilised designs. Firstly 'rolling' cannot be sensibly applied to change in position of an area. Secondly, there is no steady transfer of contact through knee flexion provided by 'rolling', rather, as the knee flexes the medial femur spins about a centre which abruptly changes to another about 30° or 40° flexion so allowing a change in articular contact position. Furthermore rather than the tension in the cruciate ligaments it is most likely that the shapes of the articulating surfaces actually drive tibio-femoral motion. The posterior shift of joint contact and femoral external rotation with knee flexion increase the extensor mechanism lever arm. Femoral external rotation allows avoidance of posterior bone impingement thereby maximizing flexion and also provides a new benefit of reducing the 'Q angle' thereby aiding patellar kinematics. A simplistic view would be that a prosthesis allowing external femoral rotation about a medial axis during knee flexion, so providing more normal kinematics might produce better results. However, although we do not believe in the four-bar linkage model, there will be some price for sacrifice of the cruciate ligaments, and at best the prosthetic articular surfaces are only approximations, all be they closer than before, to reality. To work designs will need to replicate the shapes of the naturally occurring articular surfaces. The dramatic motion seen laterally explains a number of observations the association of premature osteoarthritis with loss of the lateral meniscus, which would be well-tolerated medially, and the problems of the lateral unicompartmental replacements. Fundamental questions regarding our understanding of ligament function are asked. The knee does not move with a ligamentous rigid four-bar link guiding tibio-femoral motion. It is commonly held that taut ligaments guide joint motion. Rather physiological knee motion is far more complex and subtle than a simplified mathematical model.

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