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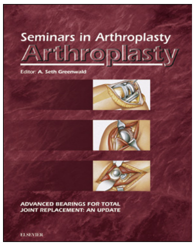

Avoiding instability: The features that matter

J. David Blaha, MD

Department of Orthopaedic Surgery, University of Michigan Health Systems, Alfred Taubman Health Care Center, 1500 East Medical Center Dr, Ann Arbor, MI 48109-5328

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ABSTRACT

When replacing the human knee, we attempt to reproduce the *stability* of the normal knee so that the patient perceives the knee arthroplasty to feel and function similar to a normal knee. Avoiding instability requires understanding the definition and implication of stability to the implant design features and the arthroplasty procedure. The purpose of this paper is to define the elements of stability in total knee arthroplasty and to explain the mechanics of the knee that will translate to optimal knee stability after TKA.

1. Introduction

A foundational principle of successful total knee replacement is proper alignment and stability, but for the purpose of this paper, alignment is considered to be optimal and stability is the issue to examine. To answer the question, "which features matter?" in terms of instability after total knee arthroplasty (TKA), we first must define stability of the normal knee because it is that stability that we try to mimic in the replaced knee.

Stability is a force vs. displacement measurement. When it requires little force to move one bone relative to another, the term is *less stiff* or *more compliant*. When motion requires more force, the term is *more stiff* or *less compliant*. When testing stability, a force is applied to the knee, and the resulting relative motion (e.g., tibia relative to the femur) can be measured. Engineers refer to the curves generated by this type of experiment as "stiffness," but because *stiffness* is not a positive term in clinical followup, orthopaedists use the inverse term *compliance* instead.

2. The force vs. displacement (stress vs strain) of ligaments

Because they are composed of longitudinal collagenous tissue, ligaments have a typical force vs. displacement behavior. In the resting state, the fibers of a ligament are wavy because they are not stretched tight. When loaded in this state, the ligament is less stiff (more compliant) and a small force longitudinally leads to greater linear displacement. This is called the toe-region of the ligaments force vs. displacement curve (Fig. 1). As the fibers become taut, the ligament becomes more stiff (less compliant) and requires more force to stretch the ligament. This is called the elastic portion of the force vs. displacement curve. As individual fibers begin to fail, the ligament elongates with less applied force, becoming less stiff in the plastic region of the curve [1].

3. Compliance of the knee

A number of studies were published in the 1970s that explored stability of the normal knee. In a study by Markolf

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E-mail address: jdblaha@med.umich.edu

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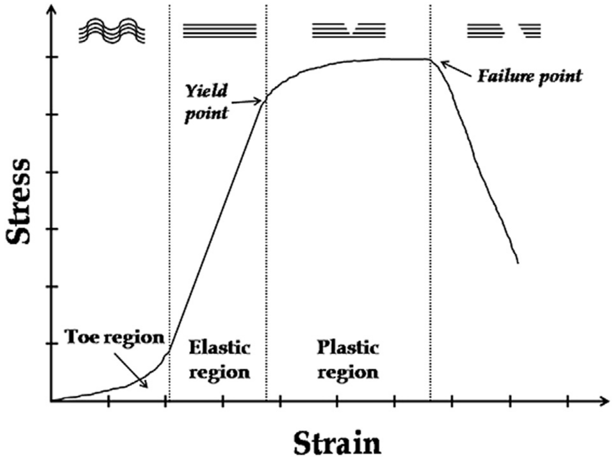

Figure 1 – The force–displacement test for ligaments is called a "stress–strain" curve and shows three regions of force–displacement response. Early in loading a small force causes considerable displacement. This is called the "toe region" of the curve. After a certain amount of displacement, the ligament enters the "elastic region" of the curve and becomes markedly more stiff. Finally, if enough force is applied, the ligament begins to fail at its "yield point". Ligaments "live" in the toe region of the stress–strain curve. This can be seen clinically when, in response to varus–valgus and anteroposterior stress, the tibia moves relative to the femur until it is stopped by tension in the ligament. This is the ligament moving from the toe region into the elastic region. Reprinted with permission from Woo et al. [1].

et al [2], an unloaded cadaver knee was tested. The specimen was stabilized so that, in one instance, a varus–valgus force could be applied to the knee and, in another instance, an anterior–posterior force could be applied. The resulting graph (Fig. 2) shows that the knee is most stiff to varus–valgus force vs. displacement at 0 degrees of flexion, and the knee becomes markedly less stiff with flexion up to 135°. For anterior–posterior displacement (Fig. 3), the knee is most stiff in full extension and becomes less stiff at 20 degrees of flexion. In contrast to the stiffness to varus–valgus loads, the knee then becomes more stiff to anterior–posterior load at 45° and even more stiff at 90°.

In another study by Markolf et al [3], published in 1978, the knees in living subjects were tested to evaluate *in vivo* knee stability. Of importance to this discussion, the protocol looked at the anterior–posterior stability of the knee with no muscle contraction and then with full voluntary muscle contraction. For both a male (Fig. 4) and a female (Fig. 5) subject, the knee became markedly more stiff when loaded by muscle contraction.

In a study published by Hsieh and Walker [4], the anterior–posterior displacement of a cadaver knee was tested with increasing amounts of external load. When the same load was applied, the displacement for the knee at 30 degrees of flexion decreased markedly with increasing external load (Fig. 6). Their conclusions were, "Under load bearing conditions, although the soft tissue structures were still playing a part, there was an increasing contribution to stability from the joint surfaces themselves as the compressing load was increased" [4]. And, "We believe that the geometrical conformity of the condyles to be the most important factor for the decreasing laxity under load-bearing" [4]. This conclusion is further supported by research from our lab in which we followed the motion of the knee in an open and closed kinematic chain model with intact and cut cruciate ligaments. The motion of the knee was nearly indistinguishable in trials completed with the cruciate ligaments intact and cut [5].

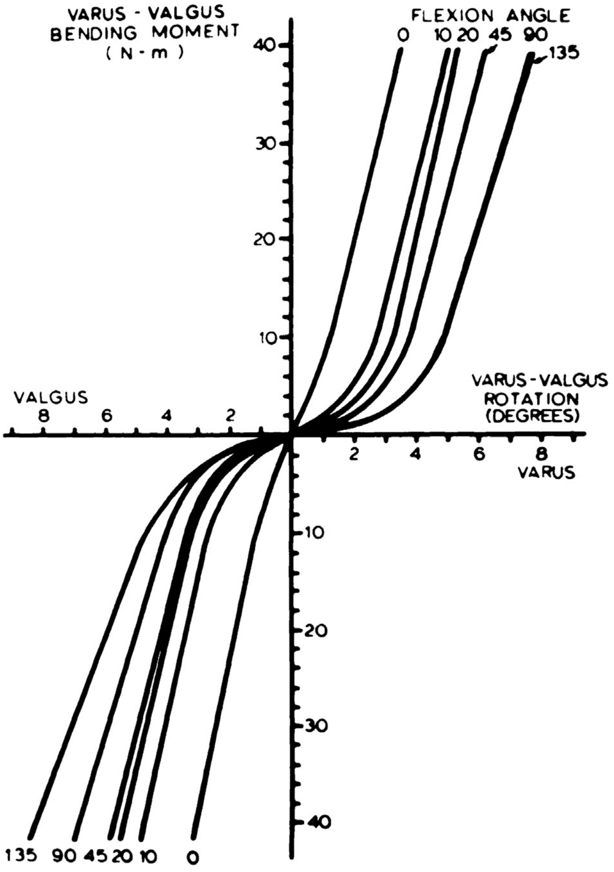

Figure 2 – Graph showing that the unloaded cadaver knee is least compliant (i.e., most stiff) to varus–valgus in full extension with compliance increasing with increasing flexion. Reprinted with permission from Markolf et al. [2].

4. "Take-home message" on stability

When external load is applied to the knee, either in the form of muscle contraction or weight bearing, the compliance of the knee decreases (i.e., it becomes more stiff and more stable). However, note that loading *decreases* the tension in the ligaments, yet the knee is *less compliant*. The only way this can happen is by the geometry of the surfaces (i.e., the congruence of the femur and tibia) imparting the stability with the ligaments doing little.

Thus we can conclude that when moving in the plane of flexion–extension without external load, the stability of the knee is not dependent on the ligaments but rather on the geometry of the articular surfaces. Without external load