# The Role of Proprioceptive Deficits, Ligamentous Laxity, and Malalignment in Development and Progression of Knee Osteoarthritis

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Local mechanical factors, such as malalignment, laxity, and a reduction in proprioceptive acuity, may play a role in the natural history of osteoarthritis (OA) as reflected by joint pain and progression of functional impairment and structural damage to the joint. Most data related to these factors come from studies of persons with OA at the knee. This report will focus on the role of these factors in functional impairment in particular, in individuals with knee OA.

Although OA does not lead to disability in all those who have clinical signs of joint damage, its impact is enormous. The risk of disability (e.g., needing help in walking or climbing stairs) attributable to knee OA in the elderly is as great as that attributable to cardiovascular disease and greater than that due to any other medical condition[1]. Based on self-reported difficulty described by persons who participated in the National Health and Nutrition Examination Survey (NHANES I), Ettinger, *et al*[2] found that the presence of symptomatic knee OA was associated with a 4-fold increase in the odds of disability (Table 1). In comparison, the increase in risk associated with heart disease or pulmonary disease was approximately 2-fold. Further, among subjects who had symptomatic knee OA and heart disease, the odds of difficulty with ambulation increased more than 13-fold, in comparison with that in subjects who had neither condition. The combination of symptomatic knee OA and pulmonary disease increased the risk 9-fold.

Some of the data I present were derived from our study of mechanical factors in arthritis of the knee (the MAK study)[3], which involved 300 participants who were recruited primarily from the community, all of whom had definite osteophytosis in at least one knee and described at least "a little" difficulty with 2 or more of the 17 items in the function subscale of the Western Ontario McMaster University (WOMAC) Osteoarthritis Index[4], i.e., all subjects had some level of functional limitation at baseline.

We are in the second 5-year cycle of this study and are currently evaluating structural and functional outcomes. The major focus of the investigation is on the role of local factors in the progression of knee OA.

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*Table 1.* Odds ratios (95% CI) for association of chronic conditions with difficulty in ambulation in NHANES I. With permission, from Ettinger, et al. J Clin Epidemiol 1994; 47: 809-15.

| | |
|---|---|
| Symptomatic knee OA | 4.42 (2.32, 8.45) |
| Heart disease | 2.27 (1.84, 2.80) |
| Pulmonary disease | 1.89 (1.52, 2.34) |
| Knee OA + heart disease | 13.62 (3.70, 50.17) |
| Knee OA + pulmonary | 9.35 (2.14, 40.92) |

The paradigm under which MAK was conceived is shown in Figure 1. We considered that systemic factors place an individual at some level of susceptibility to OA and that local factors interacting upon that milieu result in OA disease. Heretofore, local anatomic and physiologic factors that influence load distribution in articular and periarticular tissues have not been studied extensively. We have been particularly interested in those related to the knee.

In developing a paradigm of how local factors might influence disability, we utilized the definitions developed by Jette[5], who defines "functional limitations" as those pertaining to limitation in a person's ability to perform discrete actions or activities, and "disability" as a person's ability to perform socially defined life tasks expected of an individual within a typical sociocultural and physical environment. Thus, functional limitations and disability are not identical, although functional limitation may lead to disability (Figure 2). We reasoned that the identification of factors that lead to decline of physical function will be

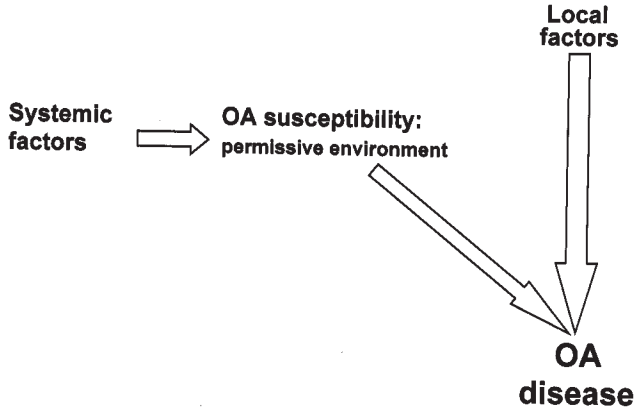


*Figure 1.* Paradigm on which the study of mechanical factors in knee OA (MAK) is based.

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helpful in developing strategies to prevent disability. As noted in a recent editorial[6], we asked the following questions:

- Can we assume that disease itself does not influence the risk of disability because of the poor relationship that is known to exist between radiographic severity and the severity of functional impairment?
- By examining the relationship between specific anatomic/physiologic aspects of disease and disability, can we learn more about the role of specific components of the disease in the functional decline of the patient?
- Is it possible that specific aspects of the disease affect function directly, i.e., will a person with a 20° flexion contracture or a varus deformity have difficulty climbing stairs due, not only to joint pain, but also to grossly abnormal joint mechanics?

With respect to the relationship between the severity of structural damage in OA, as defined radiographically, and the severity of functional limitation, the results are not entirely negative. Several studies have shown a positive relationship between radiographic severity and functional limitation. Table 2, for example, provides data from the Framingham study[7]: among subjects who had no symptoms of knee OA but a Kellgren-Lawrence (K-L) radiographic grade of OA severity ≥ 3, the odds of functional limitation (as defined by difficulty in climbing stairs) increased 3-fold and the odds of encountering difficulty in walking a mile nearly 2-fold, relative to persons with a K-L grade of 0 or 1. Similarly, in the Rotterdam study, after adjustment for hip and knee pain, radiographic evidence of hip OA, obesity, and age[8], the presence of grade 3 radiographic severity was associated with an approximately 2.5-fold increase in the risk of locomotor disability in both men and women (Table 3).

Other studies suggest a weaker relationship between radiographic severity of OA and functional limitation. This is not surprising, insofar as there are many aspects of the severity of knee OA that are not captured on the radiograph, such as the severity of pathology in the tibiofemoral and patellofemoral compartments, the presence of flexion contractures, limitation of range of motion, malalignment, joint laxity, proprioceptive defects, periarticular muscle weakness and meniscus pathology — all of which are aspects of OA that might affect the risk of disability. To date, several correlates of functional impairment in OA have been identified, based chiefly on cross-sectional analyses (Table 4). Among these, if we consider local factors other than pain, only muscle weakness and radiographic severity stand out — indicating how much we don't know about this issue.

Figure 2 provides a paradigm similar to that presented in the above editorial[6]. It became apparent to us that the local disease factors in which we were interested were, in some instances, elements of the pathology of OA and, in other cases, impairments. Specific pathologic aspects of OA (e.g., cartilage loss, malalignment, contractures, muscle atrophy, osteophytes) may result in impairments, e.g., pain, muscle weakness, gait alterations, joint laxity, and impaired proprioception. As suggested by Verbrugge and Jette[9], the pathway proceeds from pathology to impairment to functional limitation and then to disability. Personal attributes (e.g., comorbidity, physical capacity, coping skills, depression, changes in the level of physical activity) and environmental factors may influence the progression from impairment to functional limitation and from functional limitation to disability.

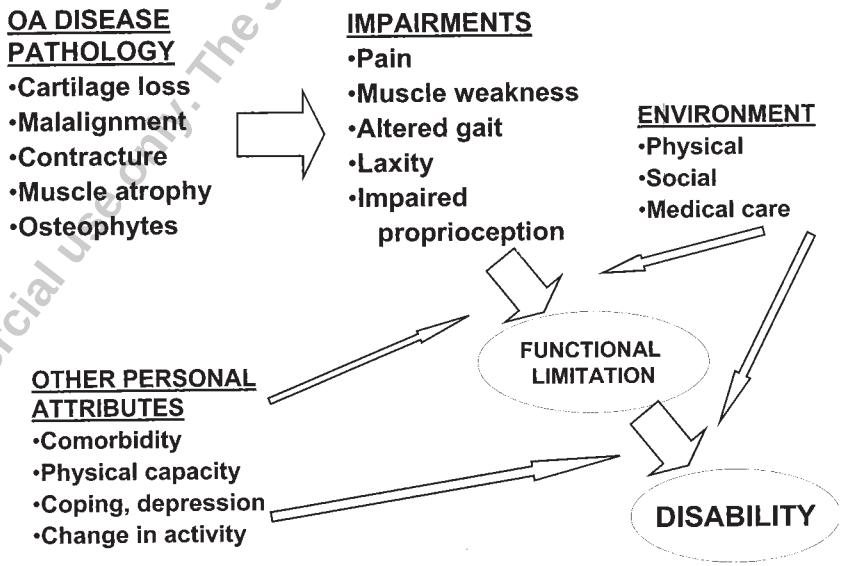


*Figure 2.* Evolution from development of pathologic changes to tissue impairment, function limitation, and disability. For simplicity, arrows are shown as unidirectional; in reality these relationships are very likely bidirectional and may be cyclic.

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*Table 2.* Adjusted relative risk for dependence upon human assistance in performance of lower extremity activities. With permission, from Guccione et al. Am J Public Health 1990; 80: 945-9.

| Activity | Proportion Disabled in Cohort | No Symptoms, Grade 2 OA (n = 214) | No Symptoms, ≥ Grade 3 OA (n = 151) | Symptoms, ≥ Grade 2 OA (n = 103) |
|---|---|---|---|---|
| Climb stairs | 47/1325 (3.5%) | 1.82 | 3.07* | 3.43* |
| Walk 1 mile | 195/1343 (14.5%) | 1.06 | 1.93* | |

* $p < 0.05$.

*Table 3.* Risk of locomotor disability and 95% confidence interval (CI) in the Rotterdam study. The results were adjusted for hip pain, knee pain, radiographic evidence of hip OA, obesity, and age. With permission, from Odding, *et al*. Ann Rheum Dis 1998; 57: 203-8.

| | Kellgren-Lawrence Grade of OA Severity | |
|---|---|---|
| | Grade ≥ 2 (95% CI) | Grade ≥ 3 (95% CI) |
| Men | 1.1 (0.9 to 2.1) | 2.7 (1.2 to 5.9) |
| Women | 1.4 (1.1 to 1.8) | 2.4 (1.4 to 4.1) |

*Table 4.* Factors associated with limitation of physical function in subjects with knee OA.

| |
|---|
| Pain |
| Psychological factors (depression, anxiety) |
| Poor self-efficacy |
| Inadequate social support |
| Periarticular muscle weakness |
| Obesity |
| Poor aerobic capacity |
| Radiographic severity of OA |

**The role of local mechanical factors in OA progression**

*Alignment*. The rationale for examining alignment is clear. In the normal knee, because of the presence of an adduction moment during the stance phase of gait, 60 to 80% of the load passes through the medial compartment. This difference in load transmission between medial and lateral compartment may explain the greater frequency of medial versus lateral tibiofemoral OA. The adduction moment essentially closes the medial compartment in gait. Varus malalignment increases the adduction moment and, probably primarily through that mechanism, leads to the progression of medial compartment OA. Valgus alignment, in contrast, increases forces in the lateral tibiofemoral compartment and the risk of progression at that site. Schouten, *et al*[12] reported a relationship between the subject's recall of having been bowlegged or knock-kneed in childhood and the progression of knee OA.

In our own studies[11], the severity of varus deformity at the knee correlated with subsequent narrowing of the medial tibiofemoral compartment (r = 0.52), and the severity of valgus deformity with subsequent narrowing of the lateral tibiofemoral compartment (r = 0.35). There are surprisingly few additional reports of correlations between risk factors for progression and radiographic joint space width, in which the latter has been considered as a continuous measurement. To place this into some context, when we examined the relationship between body mass index (BMI) and the progression of medial compartment narrowing, we found the value for that relationship was about 0.18, i.e., somewhat lower than that for varus-valgus malalignment.

As shown in Figure 3, varus malalignment is associated with a 4-fold increase in the odds of progression in the medial tibiofemoral compartment, in comparison to non-varus knees. Even when the referent group comprised knees with neutral alignment or mildly valgus knees, varus increased the odds of medial progression. Results for lateral progression in valgus knees were similar. The link between malalignment and functional impairment may be mediated through pain or muscle weakness, or may be due to a direct effect of the deformity. We evaluated this with a functional measure, the chair-stand test, in which the time required by the subject to stand 5 times from a seated position is recorded. The number of stands is then converted into the stand rate per minute; the higher the value, the better the patient's function. We looked at the change in chair-stand rate between the baseline evaluation and a followup examination 18 months later in subjects in whom malalignment was not present in either knee (i.e., ≤ 5°), in subjects in whom malalignment > 5° was present unilaterally, and in those in whom malalignment was present bilaterally.

As shown in Figure 4, subjects with bilateral malalignment had, on average, a greater decline in chair-stand rate (losing 3 chair stands/minute) than those without malalignment in either knee (who had no change in chair stand rate) between baseline and 18 months. This difference persisted after adjustment for knee pain, age, sex, and BMI[10]. Unilateral malalignment at baseline doubled the odds of a decline in function, while malalignment of both knees tripled the odds[10].

*Joint laxity.* Laxity, which is defined as abnormal rotation or displacement of the tibia, relative to the femur, can abruptly produce large displacements of the articular surfaces, alter congruity and contact sites, and increase local shear and compressive stresses. Varus-valgus laxity increases with age, is greater in women than in men, is associated with a

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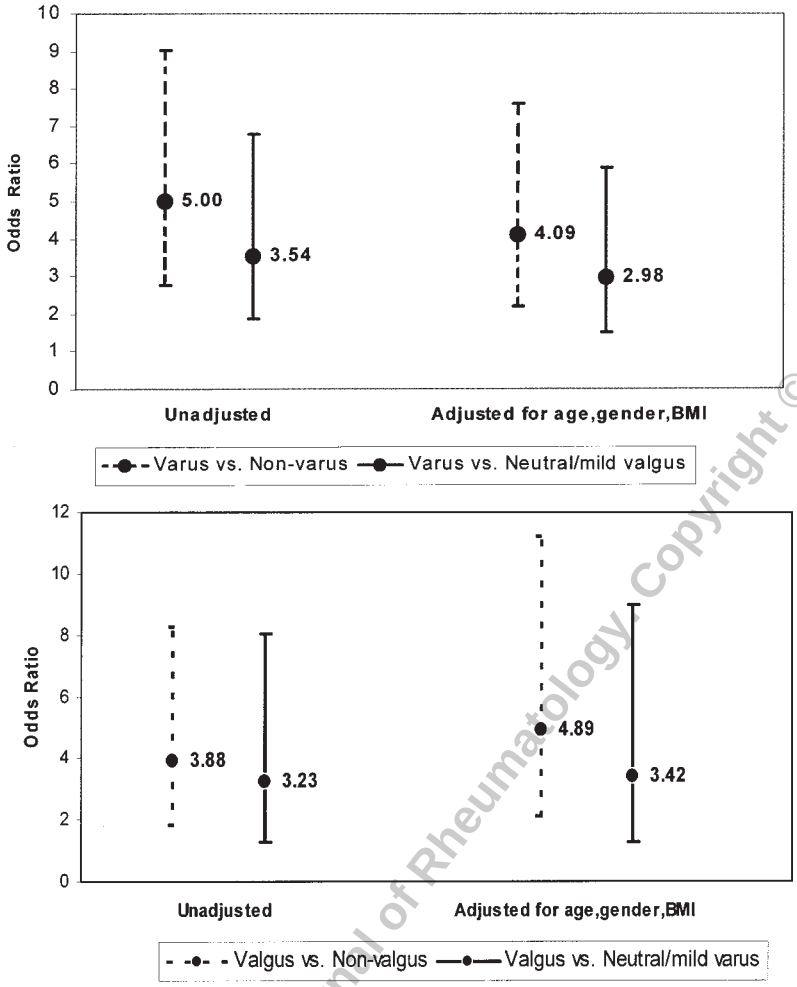


*Figure 3*. Odds ratios for progression of medial (upper panel) and lateral (lower panel) tibiofemoral compartment OA. Effects of valgus and varus deformities. With permission, from Sharma, *et al*. JAMA 2001;286:1288-95.

greater risk of OA after ligamentous injury, and appears to modify the strength-function relationship.

When we divided subjects into low laxity and high laxity groups, we found a significant difference in scores on the physical function subscale of the WOMAC, with poorer function in the high laxity group. Similarly, this group demonstrated poorer performance in the chair-stand rate[13] (Table 5).

*Proprioception*. Sensory input from the extremity (including knee joint structures) provides muscle activity that influences movement and joint stability and is important in protecting the joint from injury. Increasing proprioceptive acuity may lead to better spatial and temporal coordination of limb position and muscle activity and thereby to more normal load distribution. This may result in a decrease in joint pain, improvement in function, and a delay in the progression of structural damage, although it remains to be shown that those premises are correct.

Proprioceptive acuity declines with age, is less accurate in sedentary than in active elderly subjects, and less accurate in both arthritic and nonarthritic knees of OA subjects than in knees of age- and sex-matched control subjects[14], and is modestly improved by orthotics or muscle training. Several studies have shown that proprioceptive acuity in knees of normal subjects and in those with OA may be improved with interventions as simple as an ace bandage, neoprene sleeve, bracing, or exercise. Whether the improvement in proprioceptive activity leads to improvement in joint pain and function, however, is unclear. Interventions that improve proprioception have multiple effects; it is not clear which is important in improving function and which is not. For example, it is well recognized that exercise may decrease joint pain and improve function in patients with knee OA, and that it improves proprioception. However, it also improves endurance, reduces arthrogenous reflex inhibition of the quadriceps muscle, decreases comorbidity, results in

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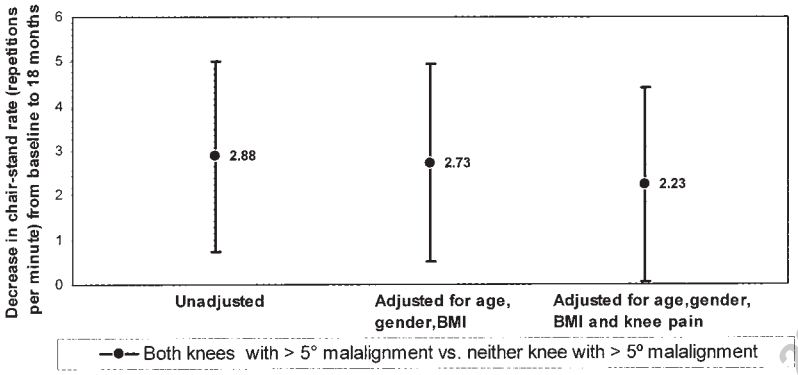


*Figure 4*. Relationship between malalignment and decline in chair-stand performance. With permission, from Sharma, *et al*. JAMA 2001;286:1288-95.

*Table 5*. Functional status, mean ± standard deviation in patients with knee OA, in relation to severity of ligamentous laxity. With permission, from Sharma, *et al*. Arthritis Rheum 1999; 42: 25-32.

| Severity of Laxity | WOMAC Physical Function Score | Chair-Stand Rate |
|---|---|---|
| Low | 20.8 ± 13.8 | 4.0 ± 1.8 |
| High | 26.5 ± 13.3* | 3.5 ± 1.8 |

* 95% CI for difference in WOMAC score between low and high laxity groups = 9.9 to 1.5.

weight loss, and improves psychologic status. The extent to which an improvement in proprioception, in contrast to improvement in one of these other factors, is important in improving function (and pain) is not clear.

We have reasoned that if local factors that predicted change in function over time could be identified, interventions might be designed to retard or prevent functional deterioration. As measures of functional limitation we used the Physical Function Scale of the WOMAC and chair-stand performance, and examined outcomes in relation to the level of physical function at baseline. We used logistic regression techniques and adjusted for age, sex, BMI, and knee pain. After adjustment, we found that mitigating factors included social support, self-efficacy, aerobic exercise, and good mental health status. We found that each 3° increment of ligamentous laxity was associated with an increase of about 1.5-fold in the odds of a poorer outcome. With respect to outcomes in the chair-stand test, each degree of proprioceptive inaccuracy was associated with a 1.23-fold increase in the odds of a poorer functional outcome. Factors that protected against this deterioration included quadriceps and hamstring strength, an increase in hamstring strength between baseline and 18 months, and enhanced self-efficacy and good emotional function, as judged by scores on the Medical Outcome Study Short Form-36 instrument.

In summary, among individuals with knee OA, poor WOMAC Physical Function outcome over 3 years was increased by greater varus-valgus laxity, BMI, and knee pain, and was diminished by better mental health status, performance of aerobic exercise, and higher scores for self-efficacy and social support. Deterioration in chair-stand performance over the 3-year interval was greater in the presence of poorer proprioceptive function and was mitigated by greater baseline quadriceps and hamstring strength, greater self-efficacy, and higher emotional function scores. Therefore, our 2 measures of functional outcomes, i.e., the WOMAC and the chair-stand test, identified different factors contributing to functional decline. These tests may help identify subjects with knee OA who are at greater risk for progressive functional limitation and are, therefore, candidates for supervised rehabilitation programs and for implementation of self-management strategies aimed at prevention of disability.

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