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Analysis of Knee Adduction Moment and its Correlation with Compressive Stress in Knee Jointfor Varus OA

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Abstract*—Varus knee OA is a very common form of arthritis due to structural abnormalities of legs. It causes pain and stiffness in the knee. It changes the malalignment of knee, which may increase natural postural sway in medio-lateral direction and increases falling risk. Knee adduction moment and compressive stress are two main factors in knee OA. Severity of knee OA depends on the KAM as KAM increases it also increase the compressive stress that exerts more pressure on knee that results in painful knee. This paper discusses calculation and relationship between KAM and compressive stress.*

Nomenclature

a	major axis (cm)
b	minor axis (cm)
d	lever arm (cm)
d_1	lever arm distance of Varus knee (cm)
P	load (N)
e	Eccentricity (cm)
I	Moment of Inertia along y direction (kg/m²)
A	Area of cross section of knee (m²)
M	Moment (Nm)
σ_m	Total stress (N/m²)
σ_d	Direct stress (N/m²)
σ_b	Bending stress (N/m²)
y	Distance from neutral axis (cm)
E	Modulus of elasticity
R	Radius

1. INTRODUCTION

The knee is a complex joint that undergoes six DOF motion. The knee is an important and strongest joint in the human body it allows the body to move while supporting the body weight.

Osteoarthritis of the Knee is a common disease that may result in pain in knee and difficulty in the walking by affecting the knee joint. It generally occurs in people age of 50 or older due to damage of cartilages that limits knee's normal movement and cause pain in knee. Because of this there is stiffness in the knee joint, inflammation and less fluid around the joint so the space between the bones in the knee joint has continued to narrow which will create more friction in the joint. Knee OA is not just a knee disease; it is a disease of tissues surrounding the joint as well. Knee OA is a disease that can affect its adjacent joints such as hip joint and ankle joint. Knee OA can affect the kinetics and kinematics of knee joint

Results of biomechanical analysis have shown that loading in the healthy knee is 62% on the medial side and 38% on the lateral side during the stance phase of gait [1]-[3]. This may result in higher chances of medial OA as compared to lateral OA.

Two factors that are responsible for knee OA-

- Knee Adduction moment
- Compressive force

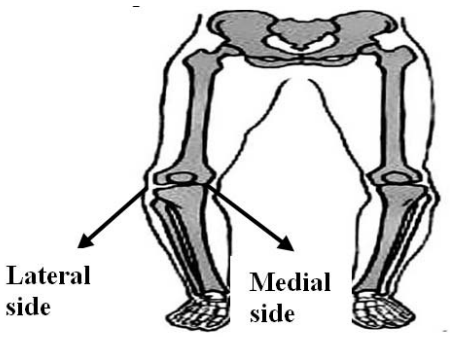


Figure 1: Schematic Diagram of human legs showing Varus Knee OA

A case of Varus knee OA has been shown in figure 1. In this OA whole bodyweight goes from medial side that create compression of bone in knee joint at medial side which results in excessive compressive stress at medial side and a painful knee to perform daily activities.

2. CALCULATION OF KNEE ADDUCTION MOMENT

Knee adduction moment is a product of ground reaction force and lever arm. When walking with greater Varus alignment KAM increases as the perpendicular distance of ground reaction force vector from the knee joint center resulting in longer moment arm.

KAM= GRF × moment arm

GRF= Body weight of person (P)

A study has shown that distance more than 3 cm between two medial epicondyles of the knee was considered as Varus situation [4].

For the calculation, we took a person whose body weight was 72 Kg and having Knee OA. So the load that is transmitted by medial side of the knee and taken as the load P acting on knee.

2.1) KAM in normal knee

To calculate KAM in normal knee, we took moment arm 0.3 cm (A study has shown that up to 3 cm distance between two medial epicondyles of the knee was considered as normal knee[4]).

KAM in normal knee = P × moment arm

= 72 × 0.3

= 21.6 Nm

2.2) KAM in Varus OA knee

To calculate KAM in Varus OA knee, we took same weight i.e. 72 Kg and moment arm distance 0.3 cm (if distance between two medial epicondyles of the knee is more than 3 cm it is considered as Varus OA knee[4]).

KAM in Varus OA knee = P × moment arm

= 72 × 0.4

= 28.8 Nm

Above equations have shown that 0.1 m difference in lever arm can increase KAM 7.2 Nm, i.e. a small increment in lever arm can increase KAM in large quantity.

So by the calculation of the KAM we can know the severity of the Knee OA because more KAM means more severe OA.

3. COMPRESSIVE STRESS

In Varus OA, gap between the bones of knee joint is reduced at medial side i.e. area reduced and load increased on the medial side of knee. Therefore, this will also increase the compressive stress on medial side.

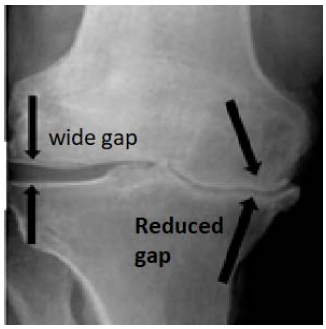
To calculate stress in knee joint, we have assumed the area of knee to be elliptical.

$$\boldsymbol{\sigma = \sigma_d + \sigma_b}$$

$$\boldsymbol{\sigma = \frac{P}{A} + \frac{M \times x}{I_{yy}}}$$

$$\boldsymbol{\sigma_m = \frac{P}{\frac{\pi}{4} \times a \times b} + \frac{P \times e \times x}{\frac{\pi}{64} \times a^3 \times b}}$$

x is the distance from mid-point of the knee joint to the point where stress has to be calculated.



A calculation has shown that if line of action of load i.e. 'e' increased 0.12 cm it increased the stress 96% more from the mid-point of knee joint at medial side[5].

4. RELATIONSHIP BETWEEN KAM AND COMPRESSIVE STRESS

So KAM is very important factor in Varus knee OA as KAM is product of GRF and lever arm, so if load i.e. GRF increases it also increases KAM which leads to bend the knee in inward direction. Bending of knee produces compression at medial side and tension at lateral side.

Therefore, gap reduced at medial side that leads bone-to-bone contact that causes extreme pain and difficulty in walking and compression at medial side leads to increase more compressive stress on knee joint at medial side.

To find out that how KAM is related to stress we took the expression of bending equation (1)-

$$\frac{M}{I} = \frac{\sigma}{y} = \frac{E}{R} \qquad \ldots.(1)$$

We took relationship

$$\frac{M}{I} = \frac{\sigma}{y}$$

$$M = \frac{\sigma \times I}{y}$$

For a specific patient dimension of knee is constant so I

and y will be constant.

Therefore, $\boldsymbol{M \propto \sigma}$

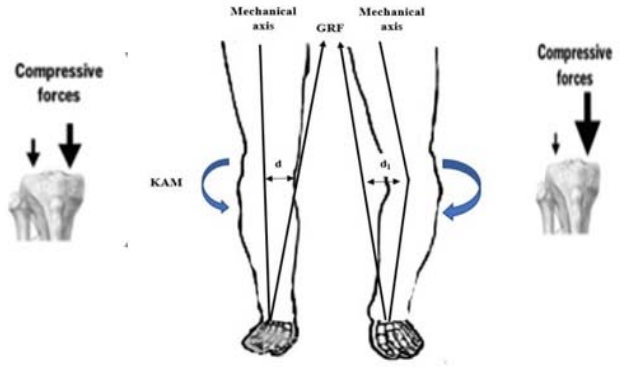


Fig. 3. Effect of KAM on compressive stress.

Now we got the relationship between KAM and compressive i.e. both are directly proportional to each other. Both KAM and compressive stress is depend on the load i.e. bodyweight.

5. CONCLUSION

In this paper, KAM has been estimated in case of normal knee and Varus OA knee at the problem side i.e. on medial side and following conclusions have been made-

- Major cause of the severity in Varus OA is bending moment due to shifting of load.
- KAM and compressive stress are directly proportional to each other.
- The stress and KAM is directly proportional to body weight, so body weight is an important factor, which increases the Varus OA.

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