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Biomechanical Analysis of Varus Knee Osteoarthritis

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***Abstract*— Varus knee osteoarthritis is a common disease due to structural abnormality of human legs. Severity of this type of Osteoarthritis can be quantified using biomechanical analysis of the Knee. Objective of this research paper was to analyze the mechanical factors that are responsible for Varus knee Osteoarthritis. Adduction moment and stresses were evaluated from lateral side to medial side. It was observed that bending stresses were responsible for increasing severity. Stresses in Varus knee is were approximately double of the normal knee.**

***Index Terms*— Knee Adduction Moment (KAM), Knee joint, Osteoarthritis (OA), Varus**

NOMENCLATURE

Symbol	Definition
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_{yy}	Moment of Inertia along y direction (kg/m²)
A	Area of cross section of knee (m²)

1. INTRODUCTION

The knee is a complex joint that undergoes 6 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 which may result in pain in knee and difficulty in the walking by affecting the knee joint. It generally occurs in people age of 50 and older but nowadays it also occurs in younger people too. Knee OA is a "wear and tear" and degenerative kind of arthritis which may occur when cartilages wears down because of excessive loading on the knee joint either on one side or both side of knee joint. So, when cartilages wears away from the joint it creates bone to bone rubbing which may result in excessive pain and difficulty in walking.

There are two kinds of knee OA:

i. Varus Knee OA
ii. Valgus Knee OA.

Mechanical factors that were responsible for Knee OA are:-

i. External Knee adduction moment
ii. Compressive Stress

Varus and valgus are two situations of knee OA. If the excessive load is going from the medial side then it is Varus OA. When the excessive load is going from the lateral side then it is Valgus OA.

Excessive joint loading at only one side i.e. on the medial side is one factor that can influence the development and progression of medial OA. 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. So, in Varus situation load on the medial side can approach to the 100% of the total compressive load.

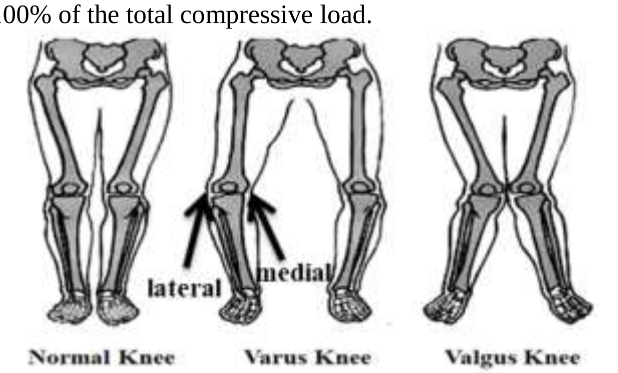

Fig. 1: Illustrates the difference between Normal Knee, Varus Knee, and Valgus Knee

As load increases it also increase the compressive stress at medial side so more pressure is applied on medial side that may result in painful knee.

Mechanical modelling

There are two kinds of mechanical factors are considered for in the present work.

a. The knee adduction moment

b. Stresses

Knee Adduction Moment (KAM):

It is the moment due to ground reaction forces (GRF) about the knee (Fig 2).

Ground reaction force = body weight

d= lever arm (cm)

KAM=GRF ×d

KAM in Normal Knee = GRF ×d

KAM in Varus Knee = GRF × d_1

$d_1 > d$

Where, **d** and $\mathbf{d_1}$ is the lever arm distance of normal knee and Varus knee, respectively.

As body weight increased KAM was also increased. KAM was responsible for bending of knee in inward direction in case of Varus OA. Direction of bending of knee due to KAM is anticlockwise.

KAM was an indirect measure of tibiofemoral contact forces. It was generated by the ground reaction force and its horizontal distance from knee center.

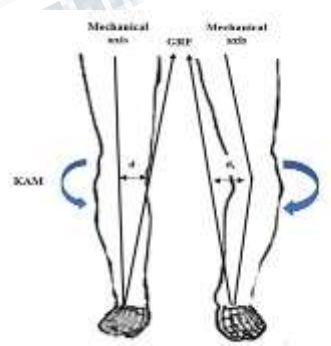

Fig.2. Schematic diagram of normal knee in left leg and Varus Knee in right leg

Stresses:

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. So, this will also increase the compressive stress on medial side. Calculation was done to show the percentage increment of stress in case of Varus OA at various sections from center of the knee and medial side.

Following were some assumptions that have been made in the calculation of stress in the knee joint -

- A left knee was taken for the calculation. Contact area at knee was assumed to be elliptical.
- Major axis 'a=8.46 cm' was initially divided from its centre into two equal parts towards medial and lateral side. Minor axis 'b' = 6.76 cm [4].
- Load due to OA is applied 'e= 0.12 cm' eccentric from the centre.
- In second step, medial side was divided into three equal sections.

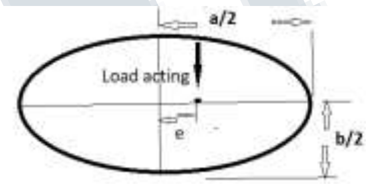

Fig. 3. Area of Knee was assumed to be elliptical whose major and minor axis are 'a' and 'b'.

Direct stress when No Varus OA

Area of contact (elliptical) 'A'= $\frac{\pi}{4}$×a×b

Second moment of area, $I_{yy} = \frac{\pi}{64} \times a^3 \times b$

Bending stresses:

$$\sigma_m = \sigma_d + \sigma_b \qquad \text{.....(1)}$$

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

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

$$\sigma_m = C[1 + \frac{16 \times e \times x}{a}] \qquad \text{....(2)}$$

Where 'C' is direct stresses = $\frac{4 \times P}{\pi \times a \times b}$

Put value of 'e' and a in equation (2)

$$\sigma_m = C[1 + 0.2269 \times x] \qquad \text{....(3)}$$

x = from center line

Stress at point O, σ_m=C×1 when 'e'=0

3. RESULTS & DISCUSSIONS

Stresses at Medial Side:

Medial side of knee joint is divided into three equal parts.

i) At 1st 1/3rd of medial side-

$x_1 = \frac{a}{2} \times \frac{1}{3} = 1.41\text{cm}.$

After putting the value of $x = x_1$ in equation (3)

$\sigma_{m_1} = 1.319\text{C}$, **stress is 32% more than O.**

ii) At 2nd 1/3rd of medial side-

$x_2 = \frac{a}{2} \times \frac{2}{3}$ = 2.82 cm

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After putting the value of $x = x_2$ in equation (3)

σ_{m_2}= 1.639C, **stress is 64% more than O**.

iii) At, 3rd 1/3rd of medial side-

$x_3 = \frac{a}{2} \times \frac{3}{3} = 4.23$ cm

After putting the value of $x = x_3$ in equation (3)

σ_{m_3}= 1.959 C, **stress is 96% more than O.**

Above 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.

An x-ray of knee of right leg has been taken to show that in case of Varus OA gap between the joint at lateral side is increased and at the medial side gap is decreased because of the compressive stress.

Fig 4. X-ray of Varus OA to validate the nature of stress calculation.

From the above stress calculation we can obtain the distribution of stress in knee joint in case of Varus OA which shown below in Fig 5. It is evident from the Fig that the stresses are increasing as the load shifts from midpoint towards medial side.

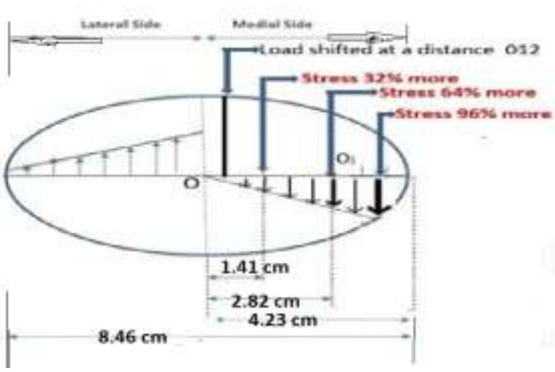

Fig 5. Stress distribution in Knee joint in case of Varus OA

Stress distribution in the edge of medial:

Let's sub-divide last section (1.41 cm) of medial side into three parts:

i) At 1st 1/3rd ,x_1 =0.47 cm

After putting the value of $x = x_1$ in equation (3)

σ_{m_1a}= 1.1064C, stress is 10% more than O_1.

ii) At 2nd 1/3rd x_2 =0.94 cm

After putting the value of $x = x_2$ in equation (3)

σ_{m_2b}= 1.1808C, stress is 18% more than O_1.

iii) At 3rd 1/3rd x_3 = 1.41cm.

After putting the value of $x = x_3$ in equation (3)

σ_{m_3c}= 1.28 C, stress is 28% more than O_1.

CONCLUSIONS

In this paper, stresses have been estimated in case of Varus OA at the problem side i.e. on medial side at various locations from the mid-point and following conclusions have been made-

- Major cause of the severity in Varus OA is bending moment due to shifting of load.
- Stresses produced in Varus OA are compressive in nature and magnitude is increasing towards medial side.
- 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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