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Kinematic Evaluation of Knee Joint Force in Men and Women Rowers

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Abstract: The article evaluates the joint knee forces in men and women of Indian continent. The force evaluation is done based on anthropometric data collected from active group of young rowers. The force calculations are based on fundamental mechanics applied to human body considered as system of rigid link and muscle forces under dynamic equilibrium. The effort is to know parameters that affect knee joint forces for both the sexes and to relate it to need for developing gender specific joint prosthesis.

Index Terms: Static equilibrium, Free body diagram, Knee Joint, Bio Mechanics

1. INTRODUCTION

Indoor rowing is considered as one of the most beneficial, complete exercises involving all major groups of muscles. It is a high order cardiovascular workout, helps burn fat and develop lean muscle mass. An ergometer is a calibrated indoor rowing machine that calculates the power or work done by the rower while rowing. Rowing is also a low-impact,high force exercise with the body weight not being supported by the legs but by the seat; and the feet are fixed onto a stationary footrest. Also this seat generally slides on a fixed bar thus making the motion of the body controlled and smooth. Hence low resistance rowing is recommended as a rehabilitation exercise. After total knee replacement, making rowing biomechanics a suitable subject to be studied for the loading on the knee during a low impact motion. Generally total knee implants are chosen according to the physique of the person rather than the sex. In this article, the difference in load on the knee joint while rowing on an indoor rowing machine for both male and female Indian candidates is discussed.

2. FREE BODY DIAGRAM

The Free Body Diagram for subject performing Indoor rowing using indoor rowing machine [3] can be discretized as multilink mechanism.

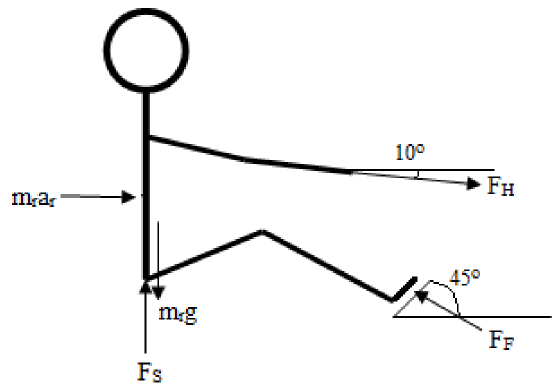

Fig. 1.Free Body Diagram while Rowing Indoors

Where:
F is: Resultant Reaction due to the Seat,
FF is Reaction at the Foot-rest,
FH is Force applied at the Handle,
Mrar is Inertial Force acting due to acceleration ar,Mrg is Weight of the Rower

The acceleration of the rower (ar) can be found out at maximum handle force condition by practical observations or by differentiating the peak velocity characteristics with respect to time. For this purpose the force time graph displayed on the machine display unit can be used. Hence static force condition at particular time interval can be used for obtaining equilibrium equation.

3. LOAD CALCULATIONS

Since the frame of reference for forces is perpendicular to direction of motion, the system of forces is in two dimensional equilibrium.

Based on this FBD diagram the equations of equilibrium can be written as:

$\Sigma Fx = 0$:

$Mrar + FH \cos 10 - FF \cos 45 = 0$ ---Eq. (1)

$\Sigma Fy = 0$:

$FF \cos 45 - FH \sin 10 - Mrg + FS = 0$ ----- Eq. (2)

These equations are solved to get the reaction at the foot-rest.The free body diagram on the lower leg so as to find the force on the knee joint can be given as:

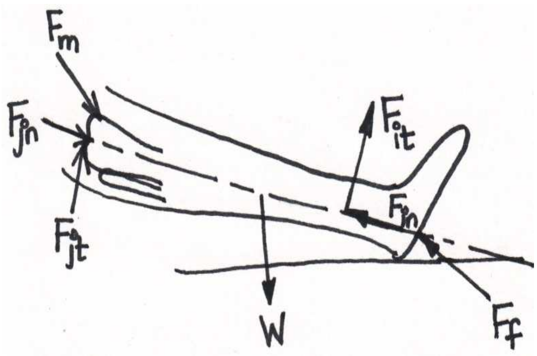

Fig. 2. Free Body Diagram of Lower Leg

Based on the angular acceleration and radius of gyration of the lower leg ,The total moment acting on the knee joint from Newton's second law of motion can be given as

$MO = Io\ \alpha$ --Eq. (3)

where MO is the magnitude of the net torque acting about the knee joint and it includes the effect of all forces acting on the knee joint. The mass moment of inertia of the lower leg about the knee joint,

$IO = mkk^2$--Eq. (4)

Where**M** is the mass of the lower leg and kk is the radius of gyration of the lower leg.

According to anthropometric collected by the author various parameters are worked out. The radius of gyration of the lower leg, when the proximal end is considered to be pivoted, is observed to be 0.65 times the length of the lower leg and the mass (**M**) is 5% of the total body weight. From the free body diagram, MO can be stated as moment due to forces acting on the lower leg as well as the net torque generated by the knee extensor muscles (MM).

Thus,

$MM = MO + (bW\cos 10) + (FF \cos 45)$---Eq. (5)

Assuming the quadriceps is the primary muscle group; then MM must be due to the rotational component (Fmt) of the force exerted by the patellar tendon on the tibia. The distance between the joint center at O and the point where the tendon is attached to the tibia is**a**,

Where a = 0.175 * length of the lower leg

Therefore:

$MM = a*Fmt$ ------- Eq. (6)

The angle between the line of pull of the patellar tendon and the long axis of the tibia is

$\beta = 240^0$. Since $Fmt = Fm \sin \beta$, The inertial forces can be calculated as the angular velocity (ω) and angular acceleration (α) are known.

Hence the magnitudes of the inertial forces,$\mathbf{F_{in}}$ and $\mathbf{F_{it}}$ which are normal and tangent to the path of motion can be calculated as:

$\mathbf{F_{in}} = m_{an} = mb\omega^2$ ------- Eq. (7)

and

$\mathbf{F_{it}} = m_{at} = mb\alpha$. ------- Eq. (8)

The angular velocity and acceleration is calculated on the basis on number of strokes per minute, the flex angle variation of the lower leg when considered pivoted at the ankle. Considering the transitional equilibrium of the lower leg in the directions normal and tangential to the path of motion, the joint force $\mathbf{F_{jt}}$ can be calculated.

$\Sigma F_n = 0$

$F_{mn} + F_{jn} + W_n - (FF/2)_n - F_{in}$

$F_{jn} = -Fmn - W_n + (FF/2)_n + F_{in}$ ----- Eq. (9)

$\Sigma F_t = 0$:

$F_{jt} - F_{mt} + F_{it} - W_t + (FF/2)_t = 0$

$F_{jt} = F_m t - F_{it} - (FF/2)_t + W_t$ ------ Eq. (10)

On the basis of the above equations the joint force at the knee can be given as:

$F_{jt} = (Fjn2 + Fjt2)\ 1/2$ ------- Eq. (11)

4. MATERIALS AND METHODS

The anthropometric data was collected from set of rowers, men and women rowers from state and National rowing team of Maharashtra state,India.The data is recorded for Maharashtra Rowing association. This is a step towards efforts to enhance the sports performance for the state rowing team. The motion study is done while rowers used Concept2 Indoor Rowing machine.[3]

For calculation purpose, the linear acceleration was considered as constant till a velocity peak was reached. The velocity is calculated by measuring the number of strokes and time thus calculating the seat velocity directly. The weight and height have been considered for a common Indian person and the handle forces have been selected according to Indian anthropometric data.[1][8]The angular velocity and acceleration have been calculated after recording the time for one stroke and the angle variation at the knee joint.

The results of joint forces calculated by equilibrium equations are listed in table No 1.

Table 1.Observed biomechanics parameters in light weight, men and women rowers.

Sr. No	Parameter	Light weight male	Light weight Female
1	Mass of the rower (m_r) (kg)	70	60
2	Acceleration of the rower (a_r) (m/s^2)	1	1.058
3	Handle force applied (F_H) (N) [2]	692	477
4	Resultant reaction at the foot rest (F_F) (N)	1062.76	533.23
5	Length of lower leg (c) (m)[1][6]	0.512	0.469
6	Mass of lower leg (m) (kg)[1]	3.5	3
7	Radius of gyration (k_k) (m)[1]	0.333	0.305
8	Angular velocity of the lower leg (/s)	2.88	3.24
9	Angular acceleration of the lower leg ($/s^2$)	3.07	3.88
10	Mass moment of inertia (I_o) ($kg\text{-}m^2$)	0.388	0.279
11	Total moment on the knee joint (M_o) (N-m)	1.19	1.083
12	Moment due to knee extensors (M_M) (N-m)	148.67	66
13	Force exerted by patellar tendon joint on tibia (F_m) (N)	4055	2028.35
14	Joint reaction force at the knee (F_j) (N)	3537.8	1767.9
15	Type of force on the knee joint	compres sive	compres sive

5. DISCUSSION

The calculations show a considerable difference in the forces working at the knee joint for male and female subjects. This may be due to the difference in muscle mass that exists in male and female subjects. Conceptually females have less muscle mass as compared to their male counterparts. This fact have reflected in difference of muscle strength upto40-50 % in the upper body and 20-30 % in the lower body in non-athletic individuals.[9] It can be noted that the knee force in males is almost double than that observed in the female joint which can be compared to the relation of muscle mass in the two individuals. Also various anatomical differences exist. This may affect the sliding or rotational motion of the knee. Thus, it can be said that the weight bearing capacity of the knee joint in males and females is different.

Now while considering the knee joint arthroplasty, even though the knee dimensions are different in each individual, according to the physical conditions and stature of the person, generally both male and female patients having the same physique are fit with the same implants. The factors such as load bearing capacity, anatomy, difference in strength of the bone are important factors in the selection of knee prosthesis. This is sighed as need to have different design for men and women for knee arthoplasty. This will result in a more compatible fit thus increasing the longevity and compatibility of the implant.

6. CONCLUSIONS

1. The knee joint force evaluated for men and women was found to be different, which is attributed to difference in the muscles mass. The effect of bone density of two sexes on joint force needs to be studied. The knee joint force in men is evaluated to be almost 50 % more than that evaluated in women.
2. Weight bearing by knee in men and women is a function of anatomical dimensions and mass of muscle involved in knee articulation.
3.There is need to develop gender specific knee implants for compatible fit, based on the fact that articulating forces acting are gender specific as well as depend on vast anatomical differences.
4. This is the pilot study to identify the need for separate design applicable to men and women for knee prosthesis used in total knee replacement surgeries.

6. FUTURE SCOPE

1. Other factors like bone density, magnitude of weight bearing activity, muscle strength, age of subject etc. have effect on the joint force. This effect needs to be quantified.
2. The data base for anthropometric data can be improved by including some more parameters like athletic and non -athletic subjects, life style, dietary pattern etc.
3. The joint force calculated here are with reference to very aggressive physical activity with the consideration that high level of activity can be gained even after the knee arthroplasty. There can be alternative philosophy of knee joint force calculation with reference to many other levels of activities, which can affect joint force calculation.

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