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Biomechanical Analysis of Knee Flexion in Osteoarthritic Patients: A Progressive Review

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Abstract*:Knee Osteoarthritis (OA) is a degenerative and irreversible disease of knee complex in which there is wear and tear of cartilage around the patellar region resulting in to pain, swelling, stiffness, restricts mobility and, sometimes the formation of bone spurs. Significant proportion of population of the age band 45-55 years and above is affected by this non-fatal disease. Literature states that several mechanical factors as well chemical imbalance have been implicated in the progression of knee osteoarthritis. The main biomechanical factors which are mainly considered for knee OA analysis are Range of motion, Internal/External rotation as well as vibrations of knee complex, Change in center of gravity, Net muscle torque, Disturbance in pressure distribution and many more. Currently there exist mainly two kinds of techniques to diagnose the Knee OA which includes Radiographic and Biomechanical analysis. Radiographic technique has various limitations like its cost effectiveness nature, usage of ionizing radiation and longer diagnosis time. This has motivated us to use noninvasive approach in form of acquiring various biomechanical factors, analyzing them and developing possible correlates between them for successful and early diagnosis of knee OA. Proposed study aims to use (i) Centre of Gravity recording (ii) Measuring the knee activity and rotation by accelerometer data (iii) Video graphic analysis of Gait pattern to measure range of motion and to develop the possible co-relation between them to have accurate, robust as well as low cost diagnosis technique for Knee OA at early stage.
Keywords: Knee Stability, Osteoarthritis, Range of Motion, Muscle Activation, Center of Gravity

I. INTRODUCTION

The knee is one of the largest and most complex joints in the body with many components. Knee injury is one of the most prevailing conditions now days and many people see their doctors for the knee problem. The origin of Anterior Knee Pain (AKP) is not yet fully clear and may have both biomechanical as well as biochemical causes. The most common problem in regards to biomechanics is abnormal movement of the patella during the flexion and extension of knee depending on muscular imbalance. Movement of patella is actively controlled by the femoral quadriceps muscle and if part of the muscle group is weak, muscle imbalance occurs and patella tends to stray away from the normal path. Wasting and weakness of quadriceps muscle are the most constant symptoms of Patellofemoral disorder. This abnormal movement of patella due to muscle imbalance causes the wear and tear of the cartilage underlying the patella bone, which is one of the causes of knee osteoarthritis (OA).

Osteoarthritis, commonly known as wear-and-tear arthritis, is a condition in which the natural cushioning between joints-cartilage-wears away. When this happens, the bones of the joints rub more closely against one another with less of the shock-absorbing benefits of cartilage. The rubbing results in pain, swelling, stiffness, decreased ability to move and, sometimes, the formation of bone spurs. Over time, joints may lose strength and pain may become chronic. They can be mild, moderate and severe. Almost everyone will eventually develop some degree of osteoarthritis.

Knee osteoarthritis (OA) is generally referred as knee non-fatal irreversible disease. The incident rate of knee OA is more in the case of elderly people, more specifically in women. It limits the functional activities and leads to loss of functional dependency and restricts the quality of life. As the average life of people is an increasing day by day, so more and more elder persons are expecting the pain free active life. In public health care domain it becomes critical and essential issue to diagnose the OA in its early stages and treat properly.

A. *The major parameters which affect the incident rate of Knee OA are [1]:*

1) *Age:* The ability of cartilage to heal decreases as person gets older.
2) *Weight:* Weight increases pressure on all the joints, especially the knees. Every pound of weight you gain adds 3 to 4 pounds of extra weight on your knees.

3) *Hereditary:* This includes genetic mutations that might make a person more likely to develop osteoarthritis of the knee. It may also be due to inherited abnormalities in the shape of the bones that surround the knee joint.
4) *Gender:* Women aging 55 and older are more likely than men to develop osteoarthritis of the knee.
5) *Repetitive stress injuries:* These are usually a result of the type of job a person has. People with certain occupations that include a lot of activity that can stress the joint, such as kneeling, squatting, or lifting heavy weights are more likely to develop osteoarthritis of the knee because of the constant pressure on the joint.
6) *Athletics:* Athletics involved in soccer, tennis or long distance running may be at higher risk for developing osteoarthritis of the knee. That means athletes should take precautions to avoid injury. However, its exercise strengthens joints and can decrease the risk of osteoarthritis. In fact, weak muscles around the knee can lead to osteoarthritis.
7) *Other illnesses:* people with rheumatoid arthritis, the second most common type of arthritis, are also more likely to develop osteoarthritis. People with certain metabolic disorders, such as iron overload or excess growth hormone, also run a higher risk of osteoarthritis

To quantify such problems, there are two methods for examination of knee OA namely Radiographic and Biomechanical Analysis. In Radiographic method, mostly MRI and X-Rays are used to diagnose the knee OA, but sometimes they do not give a clear reason for joint pain and thus suggest that other type of joint tissue could be damaged. The various biomechanical factors associated with Knee OA are as under:

8) Kinetics
9) Compressive forces
10) Muscular Power (Isometric EMG)
11) Centre of Gravity
12) Range of Motion
13) Degree of Freedom
14) Ground Reactance Force
15) Net Muscular Torque

The presented work aims to present the biomechanical analysis for knee flexion for developing the possible co-relation among various biomechanical factors.

II. LITERATURE REVIEW

It has been reviewed that different types of techniques, both invasive as well as non-invasive are reported for the diagnosis of OA. Some of them are X-Ray imaging, Computed Tomography, Magnetic Resonance Imaging, arthroscopy are having their limitations of their cost effective nature and ease of use, not suitable solution for ma screenings and repeated use.

Based on review it is found that about one fifth of population will be affected by arthritis in the U.S. by the year 2020 [2]. More than 15% of adult population in the UK has long-term health problems due to arthritis and related conditions [3]. Significant proportion of population above the age of 45 years is affected by this nonfatal, but crippling disease. Its prevalence is more in women than men. Although hip OA is more common in the western population, whereas on other side Indians and South East Asians have more incidence of knee OA. Diagnosis of OA in early stages with easy to use and effective non-invasive method is still a challenge for biomedical engineers and its possible different ways are being explored.

Table I
Previous work done on knee oa analysis

Sr. No.	Author Name	Research Tools Used	Findings & Limitation	Year
1.	K.J.Deluzio, J.L.Astephen [4]	Gait Waveform Data analysis using Principal Component Analysis	Misclassification rate of 8% was found among control group and affected group.	2007
2.	Sharma., et. Al [5]	Knee Load alignment for analysis of varus and valgus situation using radiographs	Progression of OA, defined as a 1-grade increase in severity of joint space narrowing Valgus alignment increases risk of lateral OA progression	2001
3.	Chang., et. al. [6]	Peak Knee Adduction	Greater baseline peak KAM and KAM	2015

		Movement Knee Flexion Movement Gait Biomechanics	impulse were each associated with worsening of medial bone marrow lesions, but not cartilage damage.	
4.	Hills et. al. [7]	Plantar Pressure Difference among obese and non-obese group using load distribution	For both men and women, the mean pressure values of the obese were higher under all anatomical landmarks during half body weight standing. Significant increases in pressure were found under the heel, mid-foot and metatarsal heads II and IV for men and III and IV for women. Compared to a non-obese group, obese subjects showed increased forefoot width and higher plantar pressures during standing and walking	2001

III.PROPOSED METHODOLOGY

To quantify Knee OA problems, there are two methods for examination of knee OA namely Radiographic and Biomechanical Analysis. In Radiographic method, mostly MRI and X-Rays are used to diagnose the knee OA, but sometimes they do not give a clear reason for joint pain and thus suggest that other type of joint tissue could be damaged. The various biomechanical factors associated with Knee OA are as under:

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G. Ground Reactance Force
H. Net Muscular Torque

The presented work aims to present the biomechanical analysis for knee flexion for developing the possible co-relation among various biomechanical factors.

In this work, for human motion analysis, three methods were traditionally used:

I. To locate the centre of gravity (COG) of subjects, this is easily applied to static positions.
J. Use of accelerometer for the measurement of physical moveent of knee.
K. Real time data conversion of knee flexion movement

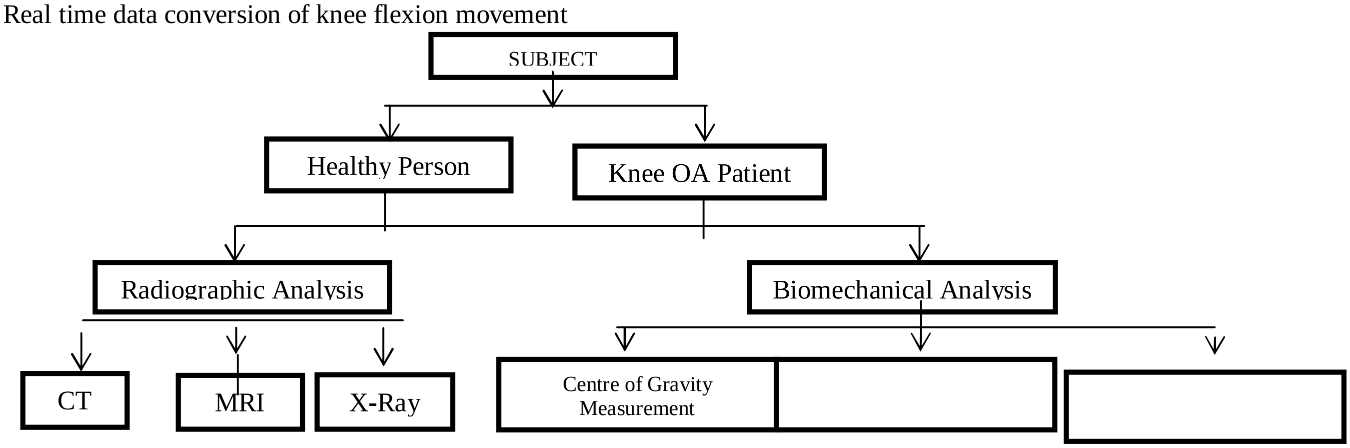

Fig.1 Block Diagram of Knee OA measurement and analysis

The inclusion criteria and various equipment and tools used in the presented study are mentioned below:

TABLE III
VARIABLES & INCLUSIVE CRITERIA OF WORK

Inclusion Criteria & Sample size of study	Variables used in Analysis	Materials used	Velocity Profile
• Age: 27 to 50 years • Gender: Both male and female • Sample size: 11 subjects (8 Males and 3 Females)	• Centre of Gravity • Range of Motion • Flexion and Extension analysis • Internal and External rotation of knee using accelerometer data • Net joint Angle	• Reaction Board for COG measurement • Measuring tape • Weighing machine • Knee belts • Markers • 2 Smart phones (One for interfacing with MATLAB and the other for capturing gait cycle videos) • Treadmill • Mobile stand	• V1 = 1.1 mph • V2 = 1.8 mph • V3 = 2.5 mph

L. Centre of Gravity Measurement using Reaction Board Method

The direct method of calculating the CG involves a device known as a reaction board. The reaction board consists of a long rigid board which is supported as each end on “knife edges”. Under one end of the board is a scale. The other end is simply elevated such that the board is level. Measurement of the CG location is based on the principle of static equilibrium (i.e., analysis of a static or stationary position of objects) in which the sum of all moments or torques acting on a system about a reference axis of rotation (A) equals zero. When the reaction board is unloaded, the equation of static equilibrium is:

$$\sum T_A = 0$$

The equation used to calculate the location of the CG relative to the reference axis is derived as follows:

$$(F_s)(L_b) = (W_{board})\left(\frac{1}{2}L_b\right) + (W_{body})(L_{cg})$$

Taking (W_{board}) *as zero we get*

$$(L_{cg}) = \frac{(F_s)(L_b)}{(W_{body})}$$

Where

F_s= Force recorded on Reaction board
L_b= Length of the board
W_{body} = weight of the body
L_{cg} = Location Length of the centre of gravity
W_{board}= Weight of the board

M. Acquisition of accelerometer data using MATLAB & android smartphone

MATLAB® supports the acquisition of data from built-in sensors on your Android™ device. With the MATLAB Support Package for Android Sensors, uses can log data or query the most recent data available from the supported sensors on your Android device. These include motion sensors like the accelerometer and position sensors like the GPS. Measurements such as acceleration, magnetic field, latitude, longitude, and altitude can be viewed on your Android smartphone and tablet. User can then analyse the data in MATLAB or build applications that make decisions based on the sensor data.

The MATLAB Support Package for Android Sensors lets you acquire and log data from the supported Android sensors to obtain the indicated measurements:

1) Acceleration on 3-axes
2) Magnetic field on 3-axes
3) Angular velocity on 3-axes
4) Azimuth, roll, pitch
5) Latitude, longitude, altitude, horizontal accuracy, speed, and course

For successful communication between Android smartphone & MALTAB

"Use MATLAB Connector to allow connection between your desktop MATLAB session and MATLAB Mobile on user Android device. User device must be able to connect to user desktop or laptop, either by being on the same network, using a VPN, or through a similarconfiguration."

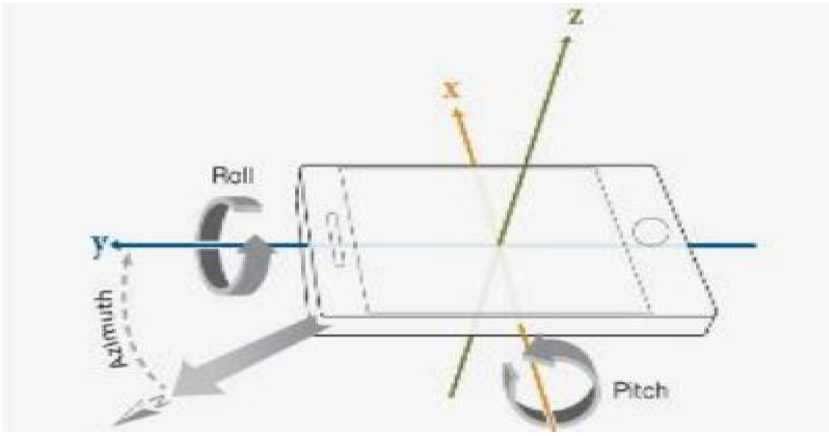

Fig. 2 Acquisition of accelerometer data using MATLAB and android smart phone [8]

N. Videographic analysis for Range of Motion analysis using Kinovea

In our moment analysis, we will be examining the amount of knee flexion allowed by two different low impact exercises. Knowing how much flexion and extension is allowed by certain exercises is of vital importance when designing a rehab program for knee OA patients. One must always consider the acceptable levels of tibio-femoral shear and joint compression forces. Maximum joint compression forces are present at around 90 degrees of flexion. Exceeding or even approaching this amount of flexion during the initial stages of rehab with a patient could prove dangerous.

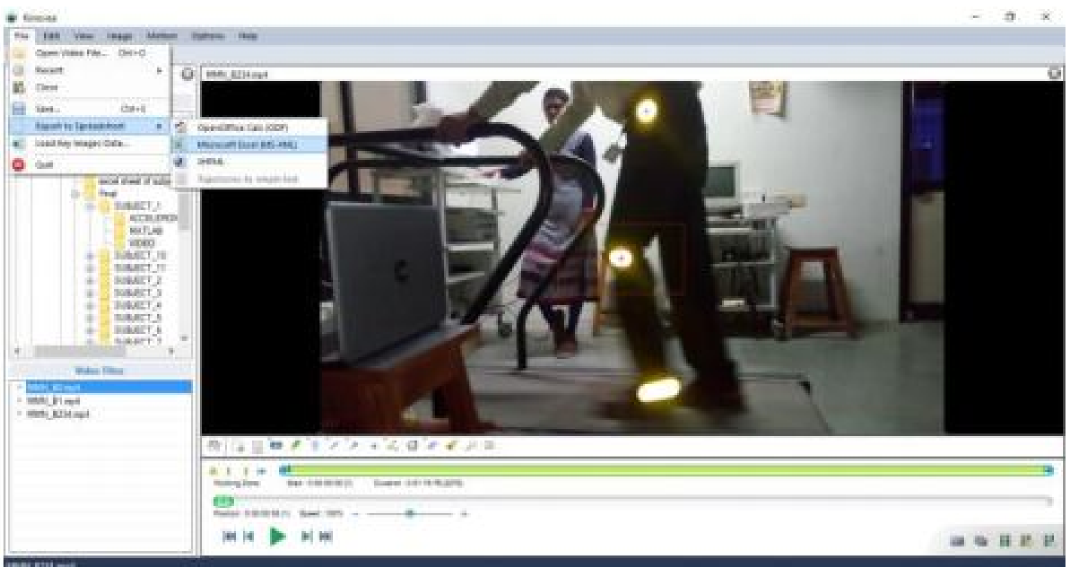

Fig. 3 Videographic analysis using Kineovea

IV. RESULTS & DISCUSSION

A. Centre of Gravity

The subjects were asked to sleep in supine position on reaction board and the reading of their normal center of gravity was recorded. The real motivation behind taking the readings of subjects while making them do the following additional activities was to check the change in load distribution in the segmentalpart of limb or whole via this method and then to compare the reading of normal subjects and affected subjects.

(1) Right leg raised (2) Left leg raised (3) Right arm raised (4) Left arm raised (5) Both arms raised.

Table IIIii

Centre of gravity analysis (normal subjects v/s affected subjects – whole population)

Mean age of subjects	42.72727	Mean of Location of COG in (%) - Normal subject	54.93645776
Age(S.D)	5.639149	S.D of Location of COG in (%)- Normal subject	5.554816411
Height Mean	167.9545	Mean of Location of COG in (%)- Affected subject	54.40849893
Height(S.D)	7.441285	S.D of Location of COG in (%)- Affected subject	1.954251588
Mean weight (W)	64.85455		
Weight(S.D)	11.10823		
BMI Mean	23.0217047		
BMI(S.D)	3.28612363		

Comparing the mean value of (%) location of COG for Normal subject & affected subject no significant differencewas observed. The probable reason behind no such significant reason may be the lesser number of availability of affected subject during the study. Referring the individual readings of the subject, it has been noticed that COG value & (%) location of COGw.r.t height of the subject is directly dependent to the weight of the subject i.e. Body MassIndex (BMI). Observing no significant difference among the normal group and affected group whilecomparing the overall mean of (%) of COG location, it gave motivation to compare the COG measurement of subjects having almost same anthropometric data i.e. Same age, height & weight in normal group and affected group.

B. Kinematic Data analysis of Accelerometer Data (Acquisition of Accelerometer data using MATLAB mobile & android smartphone)

The main motivation behind acquiring accelerometer while subject is walking under different velocity profile to check the relative orientation of the knee, hip & ankle orientation in 3 dimension which represents the external rotation while walking and also represents the internal vibration occurring due to the diseased condition or some problem present in the lower limb affecting the gait cycle.

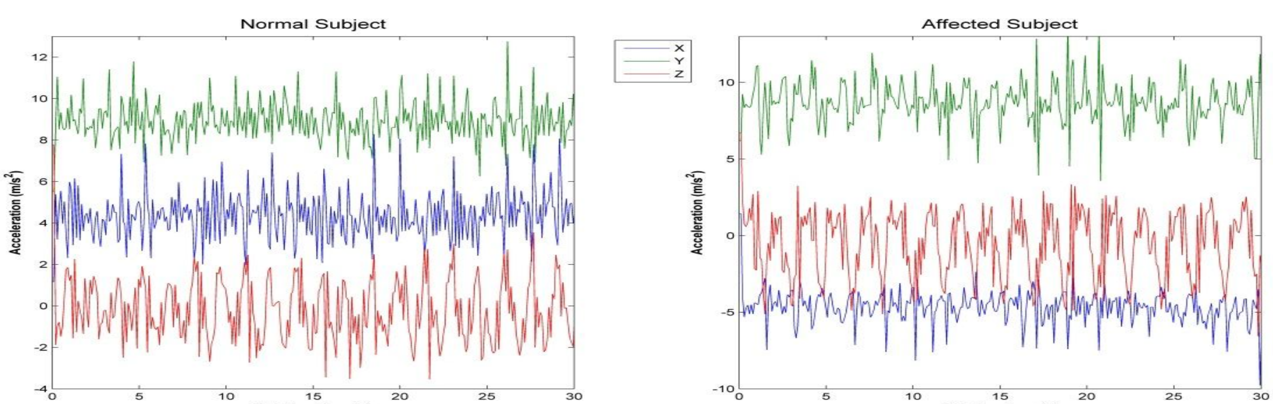

Fig. 4 Accelerometer Data acquired using MATLAB & android smartphone for normal & affected subject

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C. Videographic Analysis for Range of Motion Study

The videos were acquired during the accelerometer data acquisition and using software Kinovea the respective Flexion Extension of normal as well as affected subjects were calculated to compare the range of motion under different velocity profile.

The given below Tables represents the overall analysis of Flexion & Extension of Knee Joint for Normal v/s Affected subjects walking under different velocity profile.

Table IVv
Range of motion analysis (normal subjects v/s affected subjects)

Velocity Profile – 1 (Normal Subject)			
Subject ID	Flexion	Extension	Range Of Motion (ROM)
1	8	38	46
2	16	12	28
3	22	27	49
4	14	31	45
5	14	24	38
6	14	26	40
7	15	33	48
9	24	42	66
10	20	31	51
11	19	38	57
Mean	16.6	30.2	46.8

Velocity Profile – 1 (Affected Subjects)			
Subject ID	Flexion	Extension	Range Of Motion (ROM)
8	29	40	69
11 (Right Knee)	7	38	45
Mean	18	39	57
Std	15.556	1.4142136	16.97056275
Std	4.69515	8.6126522	10.42219853

The normal value of ROM for knee joint during walking is found between 45 – 55 degrees, comparing the values of normal as well as affected subjects among different velocity profile it has been observed among Table IV, the significant change among the ROM was observed in Normal and affected group. The change observed was either higher as well as lower than that of normal range of value. The increase in ROM was also seen in respect to the increase in the speed of velocity profile, which clearly indicates that the knee joint is the one of the most mobile joint and subjected to various forces.

V. CONCLUSIONS

In our view of different techniques for Knee OA assessment it is conclude that significant changes are observed in the analysis of knee acceleration, mainly in x and z axis which clearly indicates the presence of internal vibration in case of higher speed as well as that of affected group suffering from disorder of knee. By comparing affected and normal group, the affected subjects tends to have negative sets of values for x and z axis. Negative sign of component of velocity indicates deceleration or restriction in the direction of motion which is found in the readings of affected group. Also our findings obtained from the analysis of kinematic parameters indicated that the motion of affected subjects was containing more vibrations and was found less stable during the gait cycle at different profiles of velocity. This vibrations and instability in gait found is may be due to the involuntary intention of the subject to transfer the body weight as early as possible on the leading foot to have fall free gait cycle. This relative study also shows that, affected person tends to have more flexion and less extension as compared to the normal set of subjects in order to maintain the normalized range of motion.

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