The Impact of Open Patella Knee Cap and Designed Off-Loader Valgus Knee Brace on Muscle Activity Patterns and Joint Loading during Walk In Normal Adult – A Pilot Study

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Abstract

Objective: To assess the biomechanical impacts of open patella knee cap/sleeve and designed polycentric off-loader knee brace on knee joint movement during gait in normal adult. *Method:* Quantitative assessment for the pressure changes of strain gauges of muscles around the knee joint during normal gait with & without knee cap & brace are recorded in MATLAB and further analyzed. *Results:* The application of open patella knee cap reduces co-contractions in magnitude of lateral hamstring pair and increases those of medial hamstring pair. Contrary to it when exposed to offloader valgus knee brace same subjects had significantly vastus lateralis -lateral hamstring co-contractions greater in magnitude than those of vastus Medialis-medial hamstring. *Conclusion:* The application of open patella knee cap/sleeve without hinge joint and designed offloader knee brace attempt to redistribute the load laterally or medially respectively as needed in context to demand in normal adult.

Key words: Offloader brace, Knee Sleeve, Strain gauge sensor, Muscular loading, Gait

Introduction

The concept of unloading the affected compartment by bracing aims to correct the mechanical axis deviation. American *Academy of Orthopaedic Surgeons (1999)* classified knee braces into prophylactic, functional and rehabilitative categories. According to *Burger (1995)* the prophylactic knee braces protect or reduce severity of knee injuries from valgus stress to protect medial collateral ligaments. *Wojtys (1996)* identified that functional knee brace provide stability for ligamentous knees instability and control some degree of external knee rotation & AP joint translation. Rehabilitative braces allow protected & controlled movements in injured knees. Patello-femoral braces improve patellar tracking moderately and thereby relieve anterior knee pain (*Maurer et al, 1995; Paluska & McKeag, 2000*). They also found that unloader / offloader braces provide pain relief in osteoarthritis (OA) knees.

Harrington (1983) study indicated that varum deformity knees had a predictable loading pattern or location of centre of pressure than valgum deformity knees and hence is easily compensated. The study also found that valgus braces reduce medial compartmental loading, pain and improve the performance in

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subjects. The little change in alignment shortens the moment arm and hence lowers the external adduction and varus moment. The compressive load is shifted away from medial compartment and thus redistributes compressive load over joint surfaces. This assists to alleviate mechanical stress on the medial compartment of knee joint (*Cole & Harner, 1999*).

In off loader/unloader brace, additional valgus forces were generated by the subjects' muscles through the helical straps of the brace from one anatomical plane to another. This reaction forces on subjects leg create a resistance in flexion plane and significantly prevents full extension. The restriction in flexion motion, unload subjects' medial compartment. *Davidson et al (1997)* study showed that the dynamic forces of the hinges in the brace contribute to internal rotation of shank of tibia during extension and external rotation during knee flexion. In a similar study, it was observed that dynamic straps of an unloader brace shares the load at the knee joint. *Pollo et al (2002)* study calculated using a mathematical/computer model and reported the decreased stress in the medial knee compartment with an unloader brace.

The unloader brace improves knee stability, decreases co-contraction of thigh and leg muscles and relieves pain. It reduces compressive forces across the joint rather than direct compartment off-loading (*Ramsey et al, 2007*). The off-load shelf prophylactic knee braces provide 20-30% greater knee ligament protection (*Mortaza, 2012*).

In the normal structural abnormalities of genu varum or genu valgum, quadriceps femoris muscle especially vastus medialis oblique function is affected that limit ability to provide dynamic postural stability. According to *Nyland (2002)* study patello-femoral pain is common in those with extreme patellar tilt and lateral shift &; *Moller et al* (*1987*) stated that activation of vastus medialis obliqus is delayed compare with other quadriceps muscles and this reduces the lateral force by 25% in patellar pain syndrome patient.

The muscle response in gastrocnemius, hamstrings and quadriceps femoris are slowed significantly after fatigue. In physically demanding sports the muscle fatigue is commonly seen to alter the neuromuscular response to anterior tibial translation. The average increase of 32.5% in anterior tibial translation is seen after fatigue (*Wosjys et al 1996*) & this affects the dynamic stability of the knee. Thus, fatigue plays important role in knee injuries and its patho-mechanism.

Mediation of muscles for even distribution of load across the joint is needed for normal gait biomechanics (*Shakoor & Moisio, 2004*). So, the measurement of the muscle activation pattern and dynamic joint loading patterns helps to evaluate the extent of abnormal joint loading and alterations in the neuromuscular system in OA knee subjects (*Childs et al, 2004*).

The neuromuscular system is not effectively challenged in static positions compared to dynamic condition during the activities of daily living and sports. Majority of dynamic sport activities precisely assess single limb activities as landing force movement. The different studies (*Colby et al, 1999; Webster &*

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Gibble, 2010 &; Yayaei-Rad et al, 2013) showed that during dynamic task the genu-varum increases dynamic postural stability index and decreases the dynamic balance. Moreover strength, stability and balance are essential for protection and prevention of joint health.

During normal ambulation the force transmitted on the medial and lateral compartments of the knee is different. *Kuroyangi et al* (*2007*) study indicates that the loads on the medial compartment are 2.5 times more than the lateral compartment of the knee. There are more other studies indicating the similar concept. Also, the study found that the healthy subjects transmit 71% to 91% of total knee force through tibio-femoral compartment compared to 100% in OA. Thus, force augmentation may be a contributing factor in the development of knee OA (*Esrafilian et al, 2012*).

Published studies on the use of knee braces in OA, report biomechanical outcomes relating changes in the joint movement and posture, however a few reporting patient-derived outcomes. In summary, unloading braces may be a valid option for selected patients.

Materials & Method

The subjects were asked to walk on a level surface with and without open patella knee cap and offloader valgus knee brace to investigate the influence of orthosis on the knee alignment. Ethical approval was taken from Institute Ethical Committee, Banaras Hindu University before starting the data collection. The subjects were asked to sign a consent form and were familiarized with the study procedure.

Thirty active normal adult males participated in the pilot study. Normal male Subjects demographics are provided as (Age, 24.73±1.85 yrs; Height, 169.66±3.97 cm; Weight, 66.07±2.89 kg and BMI, 23.08±0.74) based on their grouped knee alignment, normal knee (n=14) , genu varum (n=10) and genu valgum (n=6). The knee angle was measured using a goniometry.

Exclusion criteria of study were sport injury/traumatic knee, inflammatory arthritis and metabolic disorders; along with any vestibular, proprioceptive or visual impairment.

Each subject was exposed to two interventions: (1^{st}) Open patella knee cap and (2^{nd}) Designed polycentric knee brace. Assessment variables have been six muscles around the knee joint (see data collection procedure below).

Our designed polycentric unloader knee brace had a modular structure to change the alignment based on the patient's need and could reduce the pressure at knee joint, which could be corrected to 10^0 valgus and more according to the need. Steel alloy was used instead of regular aluminum material, so that if molding is needed subject can correct according to abduction/ adduction pressure changes. This helped to have subject franchise custom made orthosis as tailor made one and does not have to wait for an orthotic's to rectify it.

Data collection procedure:

The muscular loading was assessed using strain guage sensor; with and without knee sleeve and offloader valgus knee brace of specific muscles viz. vastus-medialis (VM), vastus-lateralis (VL), semi-membranosus/ tendinosus (SS/ST), bicep femoris (BF), gastro-soleus (GS)

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and tibialis anterior (TA) muscles in a three minutes level walk.

Mechanical design incorporated a spring steel strip of length 10cm x 1cm to which strain gauges were fixed and the tip of strip acted as a mechanical pressure transducer to transfer the muscular loading to the system. The pressure changes of strain gauges in volts were captured by the differential amplifiers, which were then fed to the ADC (Analogue digital convertor) of the PIC 18F4550 microcontroller. It was finally transferred to the system via USB interface of PIC18F4550. These digital values from ADC's were received by MATLAB. The final signal processing was finally done in MATLAB. These values were recorded further and analyzed. (Data of Tables 1 & 2 shown as graph in Matlab *(Figs.1 & 2)* of same patient respectively).

Table 1: Comparative data of specific muscles of an individual subject with and without knee sleeve

Muscle variables	With knee sleeve (mean in volts)	Without knee sleeve (mean in volts)
Gasrocnemius-Soleus(GS)	**11.06**	**9.81**
Lateral Hamstrings (LH)	**7.28**	**7.48**
Medial Hamstrings (MH)	**7.63**	**7.48**
Vastus Laterals (VL)	**4.38**	**4.50**
Vastus Medialis (VM)	**4.70**	**4.50**
Tibialis Anterior (TA)	**1.30**	**1.31**

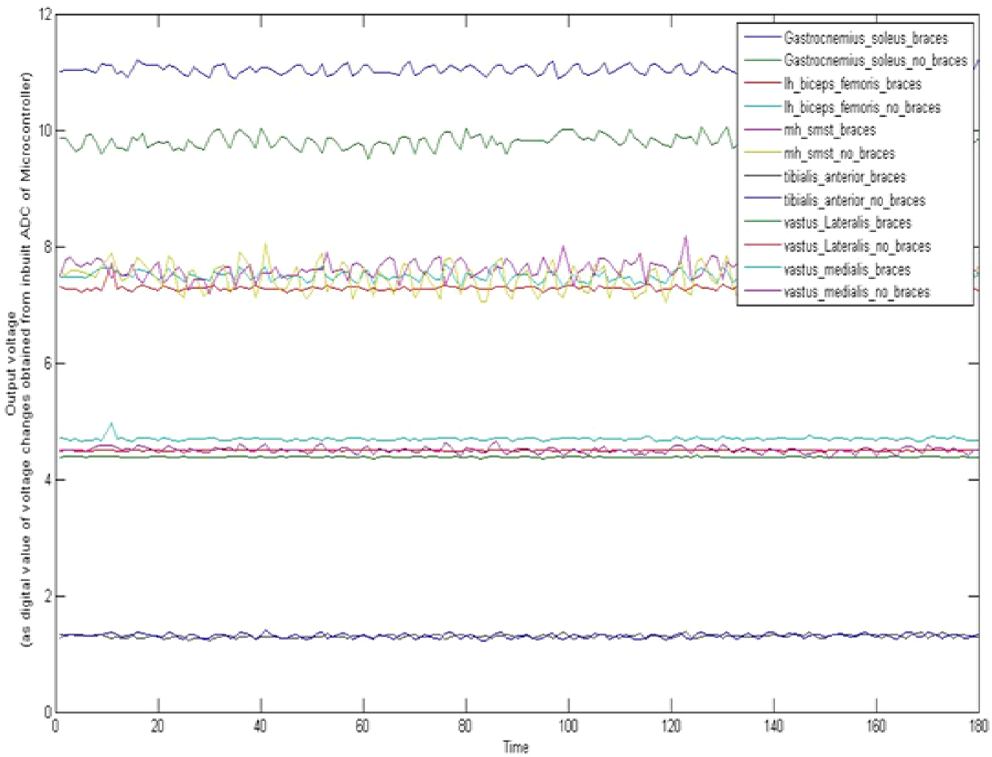

Figure 1: Comparative picture of specific muscles of an individual subject with and without knee sleeve

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Table 2: Comparative data of specific muscles of same subject with and without off-loader knee brace

Muscle variables	With knee Brace (mean in volts)	Without knee brace (mean in volts)
Gasrocnemius-Soleus (GS)	11.63	10.42
Lateral Hamstrings (LH)	7.16	7.50
Medial Hamstrings (MH)	7.86	7.51
Vastus Laterals (VL)	4.27	4.50
Vastus Medialis (VM)	4.71	4.50
Tibialis Anterior (TA)	1.04	1.06

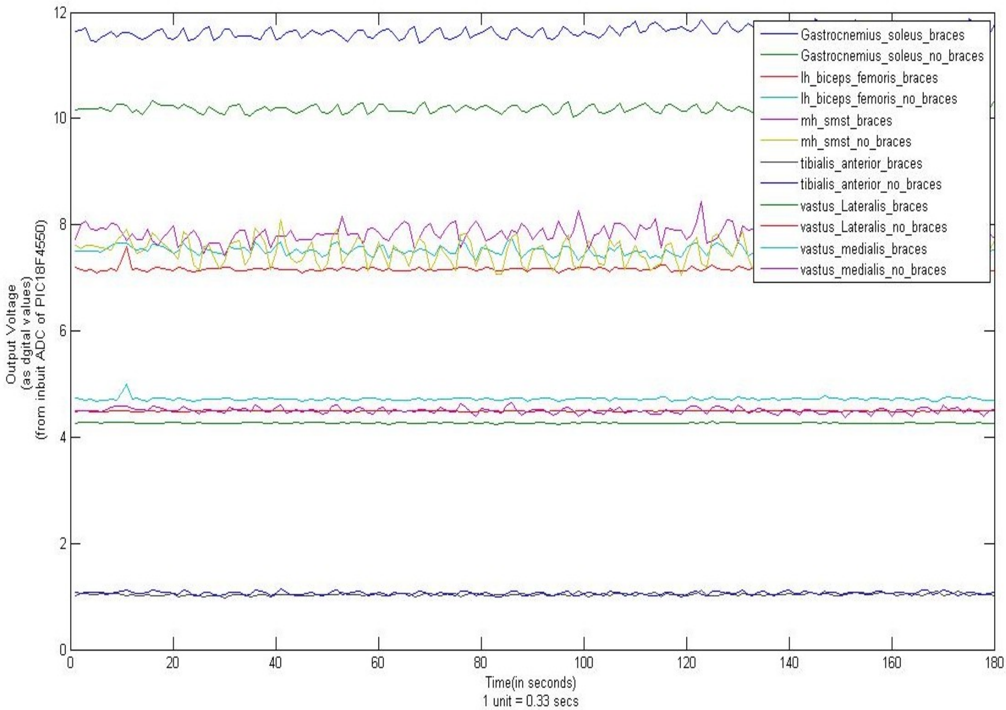

Figure 2: Comparative picture of specific muscles of same subject with and without off-loader knee brace

Table 3: Comparative efficacy of knee sleeve and valgus knee brace among loading muscles around the knee joint of normal adults (in volts)

Loading Muscles	With open patella knee cap (A) (mean±SD)	Without knee cap (A1) (mean±SD)	Paired T-test (A-A1)	With valgus knee Brace (B) (mean±SD)	Without Brace (B1) (mean±SD)	Paired T-test (B-B1)
Gasrocnemius (GS)	11.02 ±0.45	9.98 ±0.14	*15.76	11.30±0.25	10.04 ±0.09	*35.21
Lateral Hamstrings, (LH)	7.23 ±0.10	7.50 ±0.03	-*16.26	7.50±0.01	7.12 ±0.06	*40.69
Medial Hamstrings (MH)	7.78±0.05	7.51±0.03	*26.85	7.50±0.02	7.90 ±0.06	-*41.11
Vastus Laterals (VL)	4.37±0.04	4.50±0.01	-*16.39	4.50±0.01	4.27±0.02	*58.98
Vastus Medialis (VM)	4.65±0.05	4.50±0.01	*16.52	4.50±0.01	4.73±0.02	-*52.50
Tibialis Anterior (TA)	1.10±0.10	1.12±0.10	-*8.59	1.25±0.28	1.28±0.29	-*9.06

*Note: Significance (2 tailed): *P<0.005*

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Table 4: Independent T-test of muscle variables with and without knee sleeve and valgus knee brace

Variables	Group	Mean ± SD	T- test	Significance
GSNB	Knee sleeve Knee valgus brace	9.98±0.14 10.04±0.09	1.835	0.072
GSB	Knee sleeve Knee valgus brace	11.02±0.45 11.30±0.25	3.027	0.004
LHNB	Knee sleeve Knee valgus brace	7.50±0.03 7.12±0.06	34.135	0.000
LHB	Knee sleeve Knee valgus brace	7.23±0.10 7.50±0.01	15.369	0.000
MHNB	Knee sleeve Knee valgus brace	7.51±0.03 7.90±0.06	34.656	0.000
MHB	Knee sleeve Knee valgus brace	7.78±0.05 7.50±0.02	26.430	0.000
VLNB	Knee sleeve Knee valgus brace	4.50±0.01 4.27±0.02	60.685	0.000
VLB	Knee sleeve Knee valgus brace	4.37±0.04 4.50±0.01	18.205	0.000
VMNB	Knee sleeve Knee valgus brace	4.50±0.01 4.73±0.02	50.238	0.000
VMB	Knee sleeve Knee valgus brace	4.65±0.05 4.50±0.01	15.968	0.000
TANB	Knee sleeve Knee valgus brace	1.12±0.10 1.28±0.29	2.798	0.007
TAB	Knee sleeve Knee valgus brace	1.10±0.10 1.25±0.28	2.763	0.008

Note: NB (no brace); B (brace)

Data decoding and Statistical analysis: MATLAB (ver. 6.1, Math Works Inc.) was used to process data. Data was organized in Excel sheet (2002, Microsoft Corp.) and the statistics were conducted using SPSS (ver. 16.0, SPSS Inc.). A paired T-test was done to examine the difference between the mean values of muscular loading between without and with bracing in normal adults. A significance level of < 0.05 was considered for this analysis. Independent T- test was also done to examine the efficacy of open patella knee cap and offloader valgus knee brace. Comparative efficacy of knee sleeve and valgus knee brace among loading muscles around the knee joint of normal adults (in volts) is presented in Table-3. The application of knee sleeve in the study revealed GS, MH and VM increased while LH, VL and TA decreased. Thus, VL-lateral hamstring co-contractions were lesser in magnitude than those of VM-medial hamstring pair. This represents an attempt to redistribute the load medially (A & A1). On the contrary the application of offloader knee brace revealed that GS, LH and VL increased while MH, VM and TA decreased. Thus, the study indicates that vastus medialis-medial hamstring co-contraction was found to be of lesser in magnitude than those of vastus lateralis-lateral hamstring pair. It improvises loading on medial compartment of knee (B & B1). A paired t test indicates 2 tailed significance of each 6 variables with and without knee brace/ cap at P<0.005 level.

Independent t-test of different variables between two interventions i.e. knee sleeve and offloader valgus knee brace (with and without) was found to be highly significant except values of

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Gastrocnemius without knee sleeve and brace which have been insignificant (Table 4).

Discussion

A few researchers have assessed the effect of brace on muscle activity. The evidence suggested that off-loading braces may influence antagonist muscle co-contractions. In the study by *Ramsey et al* (*2007*), sixteen subjects with radiographic evidence of knee malalignment and medial compartment OA were recruited and fitted with a custom Generation II unloader brace; found that VL-lateral hamstring co-contractions were greater in magnitude than those of VM-medial hamstring. Also, *Andriacchi (1994) & Schipplein et al (1991)* studies stated that the VL greater contraction attempt to redistribute the load laterally. In *Ramsey et al* (2007) study, during neutral and valgus brace settings the co-contraction of VL-lateral hamstrings was reported to be significantly reduced from baseline in both the neutral ($p = 0.014$) and valgus conditions ($p = 0.023$); which resulted in decreased joint compression. In the present study, the subjects being non impaired adults, VL-lateral hamstring co-contractions were lesser in magnitude than those of VM-medial hamstring. Though the difference of both pairing being meager; the application of open patella knee sleeve may represent an attempt to redistribute the load medially and reflective of more stability and strength. This is in consistency with the findings of *Maurer et al* (*1995*). In the present study, the same subjects when exposed to offloader valgus knee brace had VL-lateral hamstring co-contractions greater in magnitude than those of VM-medial hamstring. This expresses an effort to re-distribute loading on the medial compartment of the knee. It will help to protect genu varum aligned normal adults as prophylactic measure and can be advocated for medial compartment OA knee persons. This study is an attempt to investigate clinical application of knee braces as indicated in a study by *Hinmann et al (2007)* which reveals that knee braces that realign knee joint in varus (our result of open patella knee brace) are opposed to those that realign in valgus direction (offloader knee brace). This is the main consistent to this study.

Polycentric offloader knee brace designed by us is 5^0-10^0 valgus and hence influence moment applied on the knee joint i.e. the magnitude of the medio-lateral force and moment arm. The resultant adduction moment applied on the knee joint decreases significantly, as that in the study by *Esrafiliaan et al* (*2012*). Few researchers (*Beynnon, 1992; Ott & Clancy, 1993; Wojtys, 1996*) observed that unloader brace compensate a portion of external load and AP joint rendition. Improvement in the medio-lateral force and the knee joint alignment decreased following use of the knee orthosis is important finding of this study. *Divine & Hewett* (*2005*) also informed that orthosis improve the knee stability in knee OA patient. However, *Niyousha et al* (*2013*) *& Singer* (*2008*) studies found that the examined functional knee brace/ sleeves had no significant effect on the knee muscle performance. *Beaudreui et al* (*2009*) study revealed that flexion and extension torques of knee and other joints of the lower limb were not significantly different between brace and non-braced conditions. In addition to this, there were

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no statistically significant differences between the brace and sleeve. They also, reported that knee sleeves decreases pain but can't be effective for knee disability.

Pollo et al (*2002*) using strain gauges and buckle transducers affixed on the custom braces in 4-8^0 valgus setting on eleven patients using three-dimensional gait analysis & reported the compressive load reduction in the medial compartment significantly by as much as 20% at 8^0 adjusting valgus angulation from normal 4^0 to 8^0. Even normal 4° valgus alignment via the adjustable hinge reduces medial compartment load than increasing tension of straps. Measurement of medial compartment load reduction has been estimated indirectly. The net varus moments were reduced using valgus brace by 11% (7.1 N-m) and load reduction was 17% on the medial side during stance phase of the gait in normal 4^0 valgus setting. The mean maximum value of the orthotic valgus moment was 0.053 Nm/kg, which represents approximately 10% of the external genu varus moment without the brace. This outcome may explain the pain relief reported by patients using such braces in clinical studies.

Anderson et al (*2003*) study using pressure transducer inserted on the medial compartment of OA knee of 11 subjects measured unloading during walk using valgus unloader knee brace but could not found unloading although there were large variations in force output, as a consequence of transducer shifted position.

Studies on the knee brace suggest full benefits are achieved between 1-2 months and doubtful beyond 6months. *Matsuno et al* (*1997*) recommended knee bracing up to 12months for subjects awaiting knee surgery and those with pharmacological risks.

Conclusion: The results of this study, suggest that knee sleeve may redistribute the load medially while polycentric offloader knee brace laterally thus, provide unloading knee in frontal plane and may decrease or increase respectively dynamic balance during sport activity as needed in context to demand in normal adult. The subjects without it might be at risk of injury during sport activity due to the reduced balance deficit.

The offloader valgus knee brace will help to protect genu varum aligned normal adults while knee sleeve will provide support to genu valgum and sport persons. The selected prophylactic brace in this study significantly inhibit athletic performance which might verify that their structure and design have caused limitation in the normal function of the knee joint but for a trance phase and enhance capability for better sports. The biomechanical indication and limitation of the off loader knee brace should be confirmed by a larger study as prophylactic measure and can be advocated for medial compartment OA knee persons.

Limitation of this study was that we have only assessed the effects of knee sleeve and offloader valgus brace on the knee joint load bearing function in normal adults. Further studies with off loader brace may be helpful to investigate the interaction and compensation of the knee joint during aging process and age related compensation in larger study group.

Better insights into normal and abnormal joint mechanics will continue to play a critical role in improved orthotic therapy and conservative treatment

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modalities more effective in the near future for prolonging the life of the natural knee joint.

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