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Relationship of the Frontal Knee Alignment Measured by the HKA-Angle with the Relative Activation of the Quadriceps Muscles

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Abstract

Purpose: The purpose of this study was to compare Hip-Knee-Ankle(HKA) angle and muscle activation ratio between vastus medialis(VM), rectus femoris(RF), and vastus lateralis (VL), and by this, to examine their relationship. It is aimed to explore how the activation ratio among the muscles involved in patellofemoral kinetics would vary in relation with the frontal alignment of the lower extremity.

Subjects and Methods: 26 healthy subjects were recruited for the study. The HKA angles were measured with radiograph. The VM, RF, VL muscle activation level were measured by surface electromyography while each participant performed 4 different types of movement (isometric knee extension, squat, ambulation, step-up) and VM/RF, VM/VL, RF/VL ratios were calculated. Pearson correlation was used to estimate the relationship between the HKA angle and the muscle ratio.

Results: There was significant moderate correlation between HKA angle and VM: RF on the left side during ambulation ($p<0.05$). Moderate correlations were also observed during step-up and squat with less significance ($p<0.1$).

Conclusion: The frontal alignment of the knee measured by the HKA angle was conditionally associated with muscle activation ratio between VM and RF (VM:RF); On the left, during ambulation, step-up, and squat, the more valgus knee tended to correlate with the more VM muscle activation ratio, which is expected to induce more stabilizing effect to the patella and its tracking. It suggests that the frontal alignement measured by the HKA-angle can affect PF kinetics. It also indicates a possibility that increase in valgus alignment of the knee, by the HKA measurement, may not act unfavorably to generate PFP.

Key Words : HKA angle, EMG, muscle activation ratio, patellofemoral, alignment

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Ⅰ. Introduction

The alignment of the knee can affect patellofemoral (PF) kinetics and kinematics. Variations of the knee alignment can cause alterations in the force balance around the patellofemoral joint and the form of movement of the patella, which in turn can lead to pathology of the patellofemoral pain syndrome (PFPS) (Fulkerson, 2002; Petersen et al., 2014).

PFPS is characterized by anterior knee pain and prevalent as much as 10 to 28% of the general population. It accounts for 25 to 40% of knee problems in sports medicine clinics (Ferrari et al., 2014). Patellofemoral pain (PFP) is exacerbated by the activities such as deep knee flexion, prolonged sitting, repetitive knee extension and flexion, and it limits various activities including knee flexion(Fagan & Delahunt, 2008; Ferrari et al., 2014). The causes of PFPS have not been clearly identified, but it is accepted PFP originates from multifactorial pathways (Bolgla & Boling, 2011).

The valgus alignment of the knee, measured by the Q-angle, has been suggested in several studies as a contributing factor to PF pain (Messier et al., 1991; Moss et al., 1992). As the Q-angle is closely connected with the action line of the quadriceps muscle, an increase in the Q-angle has been considered to increase lateral force to patella during contraction of the quadriceps, which can cause patella mal-tracking (or lateral tracking) and lead to PFP (Fredericson & Yoon, 2006; Post, 1999). However, this argument was questioned by several other studies. A closer examination showed the Q-angle did not actually represent the action line of the quadriceps (Freedman et al., 2014). It was also reported that the increase in the Q-angle correlated with decrease, rather than increase, of knee abduction moment (Park & Stefanyshyn, 2011).

On the other hand, the differentiation between valgum and varum in the frontal plane knee alignment can be also evaluated by measuring the HKA-angle (hip-knee-ankle angle) which is considered to be a gold standard method. The HKA-angle is the angle between the mechanical axis of the femur and the mechanical axis of the tibia (Cooke et al., 2007). It is measured as the angle between the line from the femoral head to the center of the knee and the line from the center of the knee to the center of the ankle. The HKA-angle is close to 0° (or 180°) in the neutrally aligned lower limb and coincides with the load-bearing axis. The load-bearing axis passes more lateral to the knee in genu valgum (HKA angle 〉 0°), and more medial to the knee in genu varum (HKA-angle 〈 0°). As much as the HKA-angle is linked to mechanical axes of the lower extremity, its measurement has been demonstrated to be valid to predict prognosis in the context of knee osteoarthritis(OA). The valgus alignment in the measurement of the HKA-angle increases risk of lateral OA progression, and the varus alignment increases risk of medial OA progression (Cooke et al., 2007; Sharma et al., 2001).

Recently, Yim et al.(2016) has suggested a possibility that the HKA-angle may be related to the muscular development patterns of the lower extremity. According to the study, the HKA-angle had an inverse relationship with the steregraphic angle of the lower extremity which may represent topology of the quadriceps. In this study, it is hypothesized that if the HKA-angle, that is, the knee alignment on the frontal plane from more valgum to more varum, affect the relative activation of the quadriceps muscles, i.e., the vastus medialis (VM), rectus femoris (RF), vastus lateralis (VL), it will influence the pattern of patellar tracking and bring a change to patellofemoral kinetics and kinematics eventually affecting pathogenesis of PFP. The purpose of this study is to investigate whether the HKA-angle is related with the activation ratios between the quadriceps muscles (VM:RF, VM:VL, RF:VL), and thus explore relationship of the frontal alignment, expressed by the HKA-angle, with the patellofemoral mechanics.

The HKA-angles of the 26 subjects were compared with each of the muscle ratios, VM:RF, VM:VL, RF:VL, under the four different movement modes; isometric knee extension, squat, ambulation, step-up.

Ⅱ. Methods

The study involved 26 healthy male (9) and female (17) adults from K University in D City(Table 1.). Before participating in the study, all the participants were oriented regarding the purpose and nature of the study and signed the informed consent according to the ethical principles of the Declaration of Helsinki. Any potential participants were excluded if they had any fractures or surgeries of lower extremities during recent six months or had any contraindications to radiograph.

Table 1. General characteristics of the subjects. (N=26)

Item	Mean±SD	
Age	19.5±1.6	
Gender	F=17	M=9
Height (cm)	166.2±7.8	
Weight (kg)	59.1±11	
Body Mass Index (kg/m²)	21.3±2.6	
HKA-angle (°) (hip-knee-ankle angle)	Right 2.7±1.8	Left 2.3±1.6

1. Measurement of the HKA-angle

Anteroposterior radiograph for the lower extremity was taken as a subject stood naturally with feet shoulder-width wide. An diagnostic KXO-80S X-ray machine (Toshiba, Japan) with digital measurement software FCR-IR348CL (APL-software-B V7.0, FUJI, Japan) was used. The HKA-angle was measured from the digital radiograph as the angle between a line drawn from the center of femoral head to the tibial interspinous groove and a line drawn from to the tibial interspinous groove to the center of the tibial plafond(Fig. 1).

2. EMG recordings

VM, RF, VL muscle activation were measured using surface electromyography (EMG)(TeleMyo DTS, Noraxon Inc., USA) with data acquisition/analysis system (MyoResearch XP Master Edition 1.08.17). To minimize skin impedance, the skin was shaved, debried by rubbing with a coarse surface 3~4 times, and cleansed with isopropyl alcohol. The EMG electrode pairs were placed over the muscle belly of the respective muscle with 25mm inter-electrode distance. The EMG signals were sampled at 1000 Hz rate, and band-pass filtered(20~45 ㎐).

The EMG signals of VM, RF, VL muscles were measured during 4 different movements composed of two static and two dynamic modes; (1) isometric knee extension, (2) squat, (3) ambulation, (4) step-up. In ambulation and step-up, foot switches were added to measure periods and phases of the movements. Measurement trials were conducted for 3 times for all of the movement modes and 30 second rest periods were given between the trials to minimize muscle fatigue.

For the measurement in isometric knee extension movement, subjects wore 2.5 kg weight cuff around their ankle and positioned their knee at 30°. Joint angle was set by hand held goniometer. They were instructed to maintain the position for 5 seconds. For squat, subjects stood naturally with their feet shoulder width wide, then flexed their knees to 45°, adjusted by goniometer, and held the position for 5 seconds. Measurement during ambulation was performed while subjects were walking for 9 m distance in their normal speeds. In step-up movement, subjects stepped up onto a step box (W×L×H=44.5 ㎝×20.7 ㎝×12,3 ㎝). When measuring for the right leg, the right leg stepped up first and the left later, and vice versa when measuring for the left.

3. EMG analysis

Raw EMG data were full-wave rectified and root mean squared(RMS). To normalize the EMG signals, maximum voluntary isometric contractions(MVIC) were obtained using isokinetic extremity system(HUMAC NORM., CSMI, USA). Subjects performed 3 trials of 5 second maximum isometric knee contraction at 30° flexion with 2 min rest between the trials. All RMS values obtained from the above experimental procedure were normalized to the MVIC data.

In the movement modes of isometric knee extension and squat, middle 3 seconds from the collected 5 second data were used for data analysis. In ambulation, a single stride interval from the heel contact to the next heel contact of one side of the leg was selected. For step-up, the single leg stance phase of the measuring leg (i.e. the swing phase of the other leg) was chosen as the interval to be analyzed.

The mean of the 3 trials represented for the EMG signal value of muscle activation in each movement mode. The VM:RF, VM:VL, RF:VL muscle activation ratio for each movement were calculated by dividing the measured EMG values of the muscle activation each other.

4. Statistical analysis

The relationship between the HKA and the muscle activation ratio(each of VM:RF, RF:VL, VM:VL) was examined using a Pearson's correlation coefficient. Statistical analyses were performed by use of SPSS(version 18.0, SPSS Inc., Chicago, IL, USA). Statistical significance was set at α=0.05 to 0.1.

Figure 1. Lower extremity alignment and measurement of HKA angle. 1. Center of femoral head, 2. midpoint of tibial intercondylar eminental spines, 3. Center of the tibial plafond.

HKA: hip-knee-ankle angle

Ⅲ. Result

It is representatively presented in Fig. 2 that the relative muscle activations among VM, RF, VL are different between the two subjects whose HKA angles are different.

The presentations of correlation between the HKA angle and the muscle activation ratio(i.e. between HKA and VM/RF, between HKA and VM/VL, between HKA and RF/VL) were different depending on the type of movement and the side of the limb(Table 2). Under α<0.05, during ambulation, the HKA angle showed moderate correlation with VM/RF(r=0.409, p=0.038)(Fig. 3) in the left lower extremity. Under α<0.1, the HKA angle also correlated with VM/RF moderately during squat(r=0.334, p=0.063) and during step-up(r=0.37, p=0.096) in the left lower extremity. The HKA angle did not show significant correlation with the other variables although the probabilities for VM/RF in isometric knee extension, VM/VL in step-up and isometric knee extension, RF/VL in squat and isometric knee extension, on the left, were comparatively closer to the significance level.

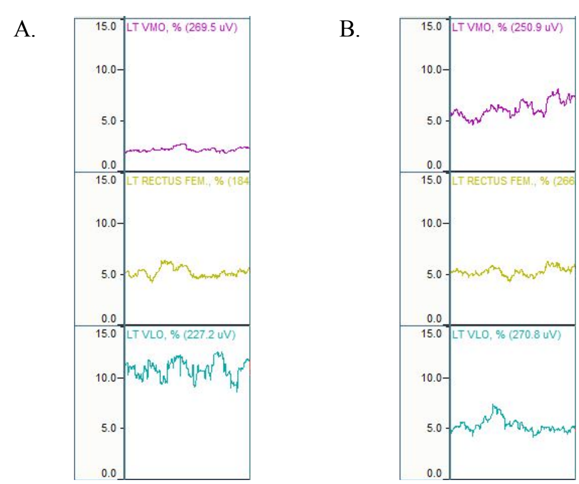

Figure 2. Variation of the relative muscle activation among VM, RF, VL in the two subjects whose HKA angles are different. A. a subject with smaller HKA angle. B. a subject with larger HKA angle.

HKA angle: hip-knee-ankle angle,

VM: vastus medialis, RF: rectus femoris, VL: vasturs lateralis

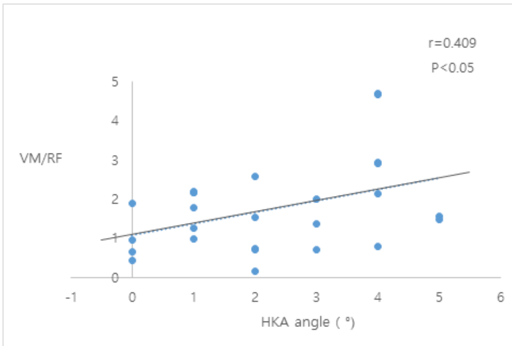

Figure 3. Correlation between HKA angle and VM:RF (during ambulation, in the left lower extremity)
HKA angle: hip-knee-ankle angle, VM: vastus medialis, RF: rectus femoris, VL: vasturs lateralis

Table 2. Correlation(r) between HKA angle and muscle activation ratio

Correlation(r) with HKA		R	L
Isometric knee extension	VM/RF	-0.072	0.265
	VM/VL	-0.048	0.232
	RF/VL	-0.263	-0.244
Squat	VM/RF	0.041	0.37a
	VM/VL	0.179	0.061
	RF/VL	0.098	-0.234
Ambulation	VM/RF	-0.084	0.409b
	VM/VL	-0.055	0.091
	RF/VL	0.02	-0.084
Step-up	VM/RF	-0.039	0.334a
	VM/VL	0.082	0.311
	RF/VL	0.145	-0.075

HKA angle: hip-knee-ankle angle, VM: vastus medialis, RF: rectus femoris, VL: vasturs lateralis
a $p<0.1$, b $p<0.05$

Ⅳ. Discussion

The relative muscle activation of VM, RF, VL, located from medial to lateral side, correlated with the HKA angle to moderate degree in a limited manner. The correlation varied according to the type of movement, muscle ratio pairs, and the side of the body. The most clearly appeared correlation was that the muscle activation ratio of VM relative to RF increased as the HKA angle increased in the left lower extremity; it was evident during ambulation (r=0.409, p=0.038) and considerable during step-up (r=0.37, p=0.096) and squat (r=0.334, p=0.063). In other words, it indicated that, on the left, during walking, stepping-up, and squatting where weight bearing activities are involved, as it gets more genu valgum with increase of the HKA angle, the use of VM relative to RF tended to increase. This tendency for the increase of relative VM activation over RF has also shown weakly in the isometric knee extension movement mode although it was short of statistically significant level (r=0.265, p=0.19). In addition, the weak tendency of increase of muscle activation ratio between VM and VL can be observed, below the significance level, on the left during isometric knee extension (r=0.232, p=0.255) and step-up (r=311, p=0.122).

From the previous studies, VM was considered to provide medially stabilizing force to patella (Ott et al., 2011; Pal et al., 2011; Pattyn et al., 2011; Tsakoniti et al., 2008). When the medially located VM's relative activation increases as the HKA-angle increases, more medial stabilization will be provided to the patella. It can contribute to stabilizing patella-tracking and consequently decreasing possibility of PFP.

The reason for this correlation has probably arisen from internal mechanism of the body to provide medial stabilization by increasing activation of the more medially located muscle to compensate for the increased knee abduction moment due to larger valgum. Similiar relationship between muscle activation change and the knee alignment has been described for sagittal plane alignment. For example, the alteration of the alignment on the sagittal plane such as knee flexion by contracture, which produces external knee flexion moment, was associated with change in activation of the quadriceps muscles to create internal extension moment (Levangie & Norkin, 2011).

These findings from our results may partially suggest a plausible explanation on the causes creating controversies among the studies over the Q-angle and PFPS (Freedman et al., 2014; Park & Stefanyshyn, 2011; Sheehan et al., 2010). If activation of the VM increases as the HKA-angle increases, then it could somewhat offset the lateral force even in the case of increase of the Q-angle that can increase lateral force to patella. Due to the overlaying influence from the HKA angle-related alignment that can produce opposite effect on the patella, the Q-angle increase may not necessarily result in increasing the PFP, as it was presented in the previous studies that raised questions about the effect of Q-angle on the PFP.

In the previous study, it was speculated that the different functional conditions during alignment assessment may be the reason for the controversial evidences of the Q-angle's effect on PFP (Liebensteiner et al., 2008). Meanwhile, our study reveals possibility that the HKA-angle related frontal alignment can affect PF kinetics, and looking beyond the Q-angle when assessing frontal plane tibiofemoral alignment in the context of PFP can be a clue to unveil the reasons for the controversies.

The result also showed that the strength of correlation of VM:RF with the HKA-angle varied among the different movement modes. It was strongest in ambulation mode (r=0.409) than in step-up (r=0.37) or squat (r=0.334), and weakest in open-chain isometric knee extension (r=0.265). In the different movement, the functional or dynamic alignment change, and the way and the time period that the mechanical axis of the lower extremity interact with ground reaction force change. Thus, the extent of correlation with the HKA-angle, which was measured in the static standing position, will be accordingly changed as well. As strongest correlation existed in ambulation, it is expected that the medial stabilization from relative increase of VM activation would be provided more during ambulation than during other three functional movements. Anyway, although degree of correlation varied, tendency of relative VM activation increase distributed all over the different functional movements.

The correlation has mainly shown in the left side, not particularly in the right. It can be possibly due to unequal extent of weight shift to the right compared with to the left in the weight bearing activities. Based on the studies that ambulation can present functional asymmetry between dominant right side and non-dominant left side(Nagano et al., 2011; Rice and Seeley, 2010; Uetake, 1992), it can be speculated that shifting the center of mass either to the right or left would occur to a different degree during the movement involving alternation of right and left weight bearing sides or bilateral weight bearing activity. With this asymmetry, relative position of weight-bearing line and ground reaction line would vary when it is on right leg stance compared with on the left, and therefore either one of both(left side in the result here) may have presented more correlation in relationship between muscle activation ratio and the HKA angle representing the alignment associated with mechanical axis.

The results of our study illustrate a mechanism that the variation in the frontal alignment measured by the HKA-angle can influence the muscles and thus bring change onto the patellofemoral kinetics. Contrastively, muscular change has known to affect functional alignment in the frontal plane, which eventually influences patellofemoral kinetics. The hip muscle, especially gluteus medius weakness leads to adduction at the hip joint, which in turn increases genu valgum functionally, and this has shown to be correlated with increase of PFP (Alba-Martin et al., 2015; Bolgla et al., 2008; Dierks et al., 2008; Herrington, 2014; Myer et al., 2014; Powers et al., 2003; Prins & van der Wurff, 2009; Salsich et al., 2012). These all together tell that interplay of skeletal alignment and muscular action is complexly involved in patellofemoral kinetics and the pathogenesis of PFPS.

This study includes several limitations. The measurement scale for the HKA angle, which was in 1° unit, was not fine enough when considering that the measured angle values were distributed in narrow range between 1~5°. For this reason, there were multiple same values in the HKA-angle measures, which may limit precision for analyzing correlation.

Exactly same standard for interval choice for EMG signal analysis could not be applied among different movement modes. Because the EMG signal value is expressed as%MVIC of each muscle of an individual, accurate muscle activation ratio cannot be obtained between the different muscles. The sample size was limited. Putting weight more on sensing the possibly existing correlation and lowering the type 2 error, the data was analyzed with broader significance level for the type 1 error. It is cautioned to interpret the result under consideration of these limitations.

Ⅴ. Conclusion

The HKA angle partially presented moderate positive relationship with muscle activation ratio between the quadriceps muscles, VM, RF, and VL. The correlation mainly appeared with the ratio between VM and RF (VM: RF), in the left lower extremity, and during ambulation, stepping-up, and squatting movements. It indicates, under the mentioned conditions, that the more valgus knee would have relatively increased activation of VM, which can provide medial stabilization to the patella to a certain degree.

It can be suggested that increase of the HKA angle, in other words, larger knee valgum may not predispose a person more toward PFP as far as his or her activities mainly involve movements such as walking, stair-climbing, and moderate degree of squatting due to the compensating effect of increased VM activation, at least in the non-dominant limb.

Understanding the mechanism of the PFP pathogenesis should be approached from the point of view that various alignment factors interact and come into play together. It is needed to expand the sight to include the effect from the HKA-angle when considering frontal alignment factors to PF kinetics and pathology. Those influences from the various alignments can be offsetting as well as additive. The alignment can affect PF kinetics in a direct and independent way, but also in an indirect manner through its influence on the patellofemoral muscles. Also, it needs to be noted that the effect of alignment of the lower extremity varies according to the type of functional movement, and more investigation on the patellofemoral kinetics from this aspect is warranted to better understand PFP which exacerbates differently with a different type of movement.

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