Strength Evaluation of Single-Radius Total Knee Replacement (TKR)

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Received April 12, 2004 / Accepted May 18, 2004

Artificial joint replacement is one of the major surgical advances of the 21th century. The primary purpose of a TKA (Total Knee Arthroplasty) is to restore normal knee function. Therefore, ideally, a TKA should: (a) maintain the natural leverage of the knee joint muscles to ensure generating adequate knee muscle moments to accomplish daily tasks such as rising from a chair or climbing stairs; (b) allow the same range of motion as an complete knee; and (c) provide adequate knee joint stability. Four individuals (2 peoples after surgery one year and 2 peoples after surgery three years) participated in this study. All they were prescreened for health and functional status by the same surgeon who performed the operations. Two days of accommodation practice occurred prior to the actual strength testing. The isometric strength (KIN-COM III) of the quadriceps and hamstring were measured at 60°and 30°of knee flexion, respectively. During isokinetic concentric testing, the range of motion was between 10°to 80°of knee flexion (stand-to-sit) and extension (sit-to-stand). For a given test, the trial exhibiting maximum torque was analyzed. A 16-channel MYOPACTM EMG system (Run Technologies, Inc.) was used to collect the differential input surface electromyographic (EMG) signals of the vastus medialis (VM), vastus lateralis (VL), rectus femoris (RF) during sit-to-stand and stand-to-sit tests. Disposable electrodes (Blue SensorTM, Medicotest, Inc.) were used to collect the EMG signals. The results were as follows; 1. Less maximum concentric (16% and 21% less for 1 year man and 3 years man, respectively) and isometric (12% and 29%, respectively) quadriceps torque for both participants. 2. 14% less maximum hamstrings concentric torque for 1 year man but 16% greater torque for 3 years man. However, 1 year man had similar hamstring isometric peak torque for both knees. 3. Less quadriceps co-contraction by 1 year man except for the VM at 10°-20°and 30°-50° range of knee flexion.

Key words – TKA (Total Knee Arthroplasty), single-axes, single-radius, evaluation of muscle power

Artificial joint replacement is one of the major surgical advances of the 21th century. Since the 1950s, total knee arthroplasty (TKA) has become the standard method to treat late stage osteoarthritis and rheumatoid arthritis of the knee joint [11]. As of 1997, there was an estimated 600,000 TKA operations per year in the world, and approximately 210,000 of these knee replacements were performed in the United States. For 1994 alone, costs exceeded $5 billion in the United States [7]. As shown in Fig. 1, the most common TKA consists of a metal femoral component of a bi-condylar shape, a polyethylene component to replace the tibial articular surface and a metal baseplate to anchor this plastic component into the tibia. The primary purpose of a TKA is to restore normal knee function. Therefore, ideally, a TKA should: (a) maintain the natural leverage of the knee joint muscles to ensure generating adequate knee muscle moments to accomplish daily tasks such as rising from a chair or climbing stairs (b) allow the same range of motion as an intact knee and (c) provide adequate knee joint stability. A secondary purpose for a TKA is to maintain as long as possible without further surgical intervention. Thus, the components of a TKA should not be loosen, wear out prematurely, or release polyethylene particles into the knee joint that can cause pain to intact tissues. To accomplish these purposes, it is assumed that the mechanics of an arthroplasty knee should be as similar as possible to those of an intact knee when feasible. Therefore, to allow typical knee motions and mechanics, an appropriate TKA design should replicate the locations of the normal knee axes of rotation. However, for normal knee movement, the exact locations of the axes of rotation are not uniformly agreed upon. A successful total knee replacement (TKR) should allow normal knee function. Compared to previous multiaxis TKR designs, the Scorpio TKR (Osteonics, Inc.) utilizes one fixed flexion/extension (F/E) axis, based on the premise that only one fixed F/E axis exists in intact knees (6,8). The location of the Scorpio F/E axis has been surmised to generate a longer moment arm of the patellar ligament than previous multiaxis designs. The Scorpio™

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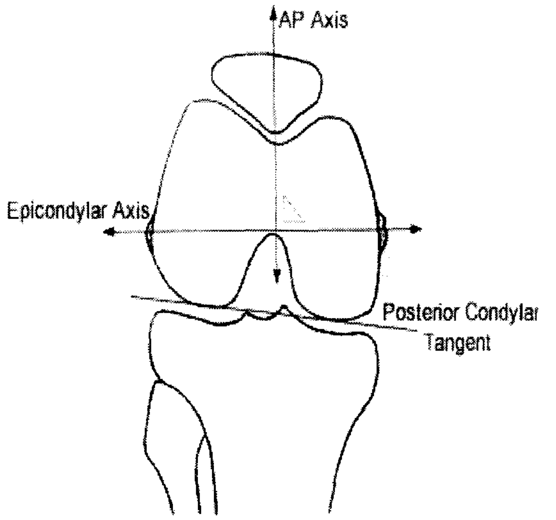

Fig. 1. Anterior view of knee region of the right leg, including the inferior surface of the distal femur, and the knee joint flexion/extension (epicondylar) and antero-posterior (AP) axes.
Churchill et al. (1998) suggested that the optimal flexion/extension axis corresponded with the trans-epicondylar line. The posterior condyle tangent line is used to demonstrate the alignment of the epicondylar axis relative to a line tangent to the posterior surfaces of the femoral condyles.

has a single radius in the femoral component that corresponds to a fixed F/E axis of rotation and that matches the epicondylar axis shown in Fig. 2(4). Hence, for our participants, would the maximum knee extensor torque of the TKR limb be similar to the non-TKR limb?

In addition, it was of interest to observe the effect of a posterior stabilized (PS) TKR design. Thus, would the

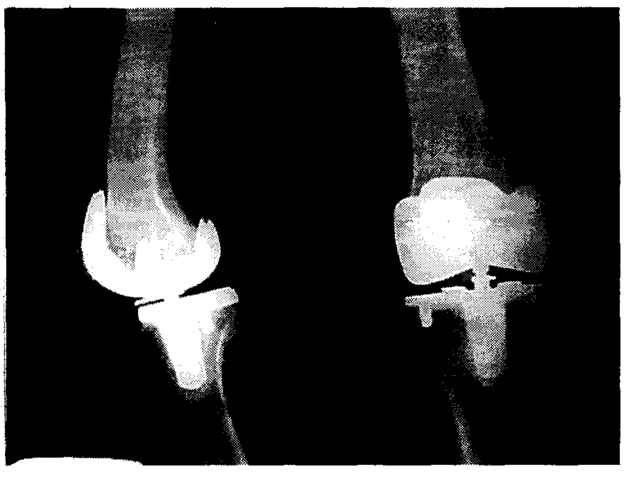

Fig. 2. Radiographs of a typical TKA of the right limb. The polyethylene tibial insert is not shown.

stabilizing post provide the restraint to replace the posterior cruciate ligament or would the participants exhibit greater quadriceps activity during isolated knee flexion, when the quadriceps serve as an antagonist to assist in posterior displacement stabilization? Thereforce, the objective of this research was to compare the maximum knee F/E torques and the quadriceps co-contraction activity during antagonist actions of the TKR and the non-TKR (N-TKR) limb during isolated knee F/E movements.

As well, It was studied about sit-to-stand (knee flexion) movement and stand-to-sit movement. Unfortunately, experimental evidence is lacking to demonstrate the knee strength and kinematic the TKA limbs during common daily activities. Although sit-to-stand movement and stand-to-sit movement are a necessary movement in Western culture, they are even more demanding than walking and stair climbing, requiring greater KN_FLEX/EXT (knee F/L) muscle moments [2]. It is potentially limiting sit-to-stand ability for someone whose knee muscle strength is compromised, for example, recent post-operation TKA patients. Based on a few existing studies whereby the biomechanical characteristics of the sit-to-stand and stand-to-sit. It appears that TKA patients exhibit compensatory adaptations to improve stability, counteract reduced KN_FLEX ROM and reduce the knee muscle and reaction force demands [12]. The primary purpose of this study was to investigate for the sit-to-stand and stand-to-sit movement, whether the use of an S-RAD (single-radius) TKA design compared to the use of an M-RAD (multi-radius) TKA design by unilateral participants would require less KN_EXT muscle activation and less abduction/adduction (ABD/ADD) and KN_FLEX muscle co-activation.

METHODS

Four individuals participated in this study. All were prescreened for health and functional status by the same surgeon who performed the operations. Two days of accommodation practice occurred prior to the actual strength testing. The isometric strength (KIN-COM III) of the quadriceps and hamstring were measured at 60°and 30°of knee flexion, respectively. During isokinetic concentric testing, the range of motion was between 10°to 80°of knee flexion (stand-to-sit) and extension (sit-to-stand). For a given test, the trial exhibiting maximum torque was analyzed. A 16-channel MYOPACTM EMG system (Run

Technologies, Inc.) was used to collect the differential input surface electromyographic (EMG) signals of the vastus medialis (VM), vastus lateralis (VL), rectus femoris (RF) during sit-to-stand and stand-to-sit tests. Disposable electrodes (Blue Sensor^{TM}, Medicotest, Inc.) were used to collect the EMG signals. The average inter-electrode distance was 2.3 cm. A reference ground electrode was attached over the distal radius of the wrist. The EMG signal (sampling rate = 1080 Hz) from the electrodes was sent to a waist pack and amplified (gain = 1000 to 10,000), then transmitted to a receiver and amplifier (MPRD-101 Receiver/Decoder unit) (CMRR = 110 dB) via an optical fiber cable. The analog EMG signal from the receiver was digitally transformed via a 12-bit A/D board.

RESULTS

The TKR limb compared to the N-TKR limb demonstrated as follows:

1. Less maximum concentric (16% and 21% less for 1 year man and 3 years man, respectively) and isometric (12% and 29%, respectively) quadriceps torque for both participants Table 1.
2. 14% less maximum hamstrings concentric torque for 1 year man but 16% greater torque for 3 years man. However, 1 year man had similar hamstring isometric peak torque for both knees.
3. Less quadriceps co-contraction by 1 year man except for the VM at 10°-20°and 30°-50° range of knee flexion Fig. 2, 3.

Discussion and Conclusions

In this study, participants exhibited TKR quadriceps torque deficits, even 3 years after their operations. However, one of the participant's results supported partially those of Berman et al. [3], who indicated that the TKR limb

Table 1. Peak torque (Nm) of quadriceps and hamstring for participant

		Concentric		Isometric	
		1 year	3 years	1 year	3 years
Quad	TKR	245.7	198.7	262.9	217.1
	N-TKR	291.6	252.8	298.9	306.2
Ham	TKR	118.0	127.7	144.2	143.2
	N-TKR	136.9	106.9	143.9	106.9

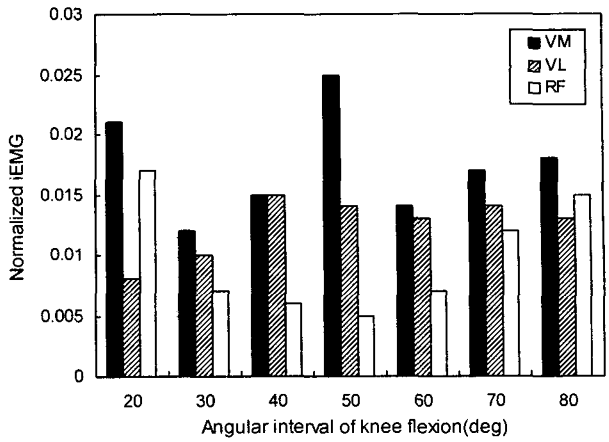

Fig. 3. Normalized co-contraction iEMG of P1 quadriceps during knee flexion for N-TKR knee.

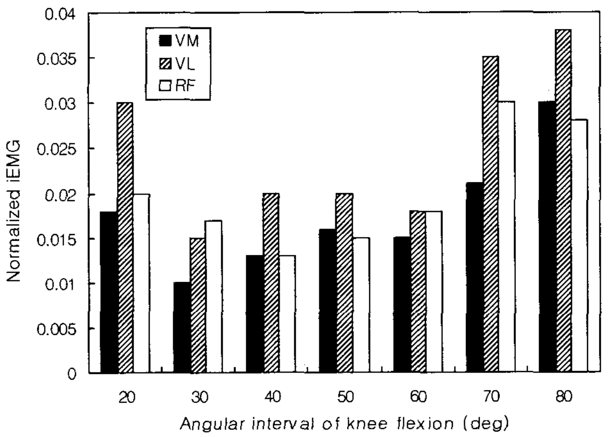

Fig. 4. Normalized co-contraction iEMG of P1 quadriceps during knee flexion for TKR knee.

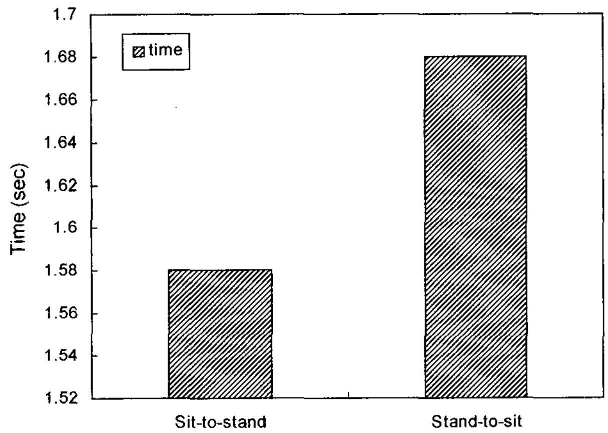

Fig. 5. Total sit-to-stand time and stand-to-sit time of S-RAD.

quadriceps strength does not recover to that of the N-TKR quadriceps by 2 years post-surgery, but the TKR hamstring strength can attain strength levels of the N-TKR knee within 7 to 12 months after surgery. Interparticipant dif

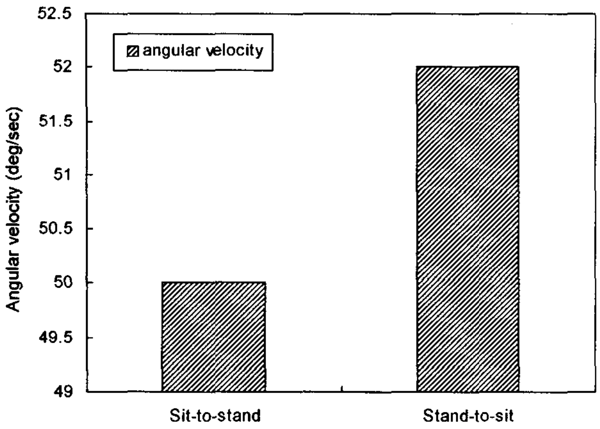

Fig. 6. Angular velocities of thigh during sit-to-stand and stand-to-sit movement.

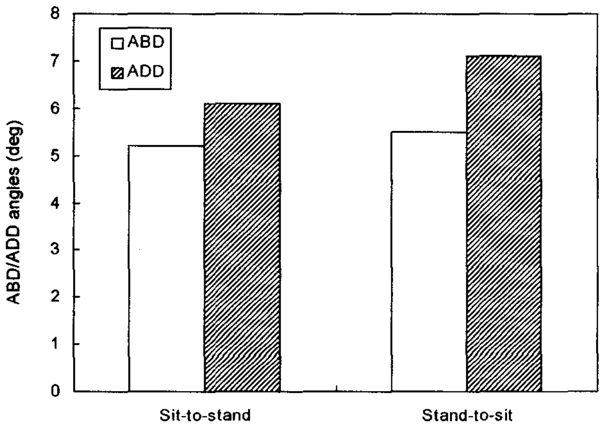

Fig. 7. ABD and ADD angles displacement of sit-to-stand and stand-to-sit of S-RAD TKA limbs.

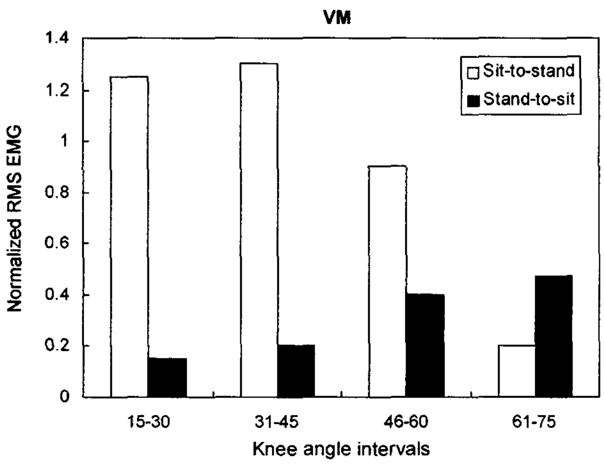

Fig. 8. VM RMS EMG for 4 angle intervals from 15 degrees to 75 degrees of knee flexion and extension during sit-to-stand and stand-to-sit.

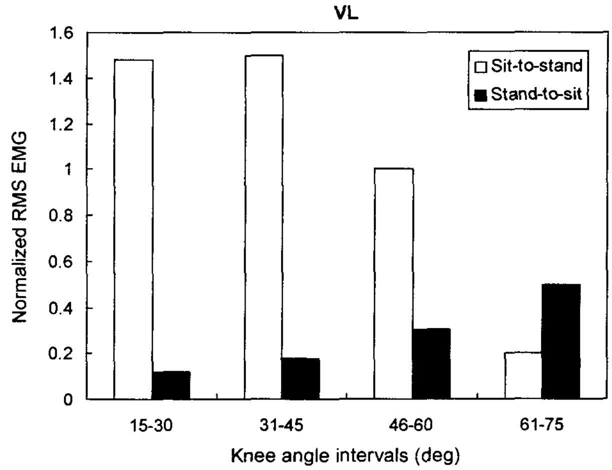

Fig. 9. VL RMS EMG for 4 angle intervals from 15 degrees to 75 degrees of knee flexion and extension during sit-to-stand and stand-to-sit.

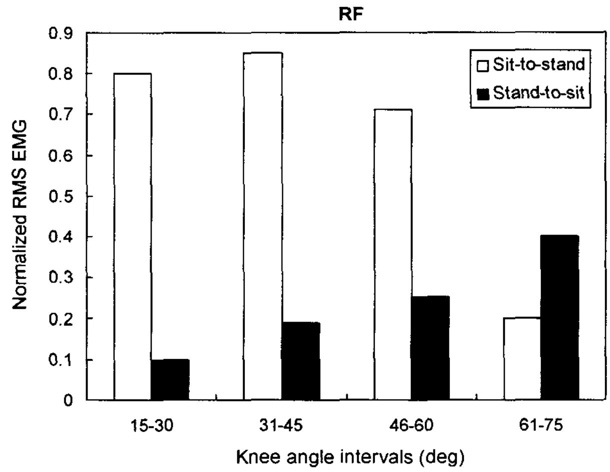

Fig. 10. RF RMS EMG for 4 angle intervals from 15 degrees to 75 degrees of knee flexion and extension during sit-to-stand and stand-to-sit.

ferences may account for our mixed findings, although the participants engaged in the same post-surgery rehabilitation and are currently physically active. It was surprising that the N-TKR quadriceps exhibited greater co-contraction iEMG than the TKR quadriceps. In addition to the antero-posterior (A/P) conformity of the prosthesis, perhaps the posterior stabilizing post provided the A/P restraint necessary. Hence, more quadriceps co-contraction EMG activity of the TKR limb was not necessary. In addition, the TKR design may not have allowed as much A/P translation as the intact knee [5,10], therefore, less quadriceps co-contraction was needed in the TKR vs the N-TKR. In this study, stand-to-sit movement time demonstrated significantly greater sit-to-stand movement time and a tendency of greater thigh flexion velocity. These findings suggest the existence of the compensatory adap tations in the knee flexion and extension movements. Although our value for sit-to-stand time and stand-to-sit time were less than time of normal old adults (1.83 sec, SD = 0.71) reported by Alexander [1], as we expected, participants used less time to stand up from a seated position than that of normal old adults. It cannot be conclusively determined from these data why this occurred. However, it is possible that knee extensor and flexor strength (i.e., the amount of knee extension muscle moment that can be produced) may have influenced the sit-to-stand time and stand-to-sit time. As a recent study showed that the participant limb could generate greater isokinetic knee extension and flexion torque than that of normal old adults [9]. As we expected, the stand-to-sit movement demonstrated 0.3° more ABD displacement than the sit-to-stand. Also, the stand-to-sit movement reached the peak ABD much later (17% more of the total stand-to-sit time and 15° more knee flexion) than the sit-to-stand movement. These findings suggested that the stand-to-sit movement could not effectively control medio-lateral stability when the knee flexion angle increased. The possible explanation is, when the stand-to-sit movement started using the short radii in the femoral component, the tension of the collateral ligaments was reduced. Thus, the stand-to-sit movement could allow the ABD motion to grow until the medial collateral ligament regained its tension. The stand-to-sit movement tended to have about 1.2° more ADD displacement than the sit-to-stand movement. Thus, during the sit-to-stand movement and stand-to-sit movement, as the knee joint moved from extension to flexion, the stand-to-sit movement tended to have unnecessary more knee ADD displacement than the sit-to-stand movement.

As predicted, The EMG of the VM, VL, and RF of the sit-to-stand movement were significantly greater than those of the stand-to-sit movement during 15°-60°movements. More muscle activation demonstrated in the sit-to-stand movement reflected greater demand on muscle efforts.

During the stand-to-sit, the quadriceps contracts eccentrically in order to counteract the flexion torque and ensure the body has a comfortable touchdown on the chair. In the current study, we found that the sit-to-stand movement had or tended to have greater VM, VL and RF EMG than the stand-to-movement. Great quadriceps eccentric and concentric EMG increased the knee extension force and flexion force and therefore increased the knee extension torque and flexion torque.

In conclusion, the TKA limb increased the quadriceps eccentric contraction and concentric contraction in order to provide adequate knee extension moment and flexion moment during the stand-to-sit and sit-to stand. Also, the TKA limb participants exhibited an unstable knee by showing greater ABD/ADD displacement and VM, VL and BF co-contraction than that of the normal old adults.

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<The Fig. 5> shows that the average time for the participants to accomplish the sit-to-stand movement was 1.59s, and stand-to-sit movement was 1.68s.

<In Fig. 6> the participant TKA movement tended to have 2°/s less sit-to-stand angular velocity than stand-to-sit angular velocity.

<The Fig. 7> shows ABD and ADD angles displacement of sit-to-stand movement and stand-to-sit movement of participant TKA lims. The ABD displacement tended to have about 0.3°less sit-to-stand angle 5.2 deg than stand-to-sit 5.5 deg. The ADD shows 6.1 deg and 7.2 deg each other.

<The Fig. 8-10> showed the quadriceps EMG results for the participants TKA. The VM RMS EMG of the TKA limb demonstrated significant different from 15°to 75°; all phase of knee flexion and extension. The VL of the stand-to-sit movement also demonstrated significant less RMS EMG than that of the sit-to-stand movement from 15° to 60° of knee extension. Similar to the VM and VL, the RF of the stand-to-sit movement showed less RMS EMG than that of the sit-to-stand from 15° to 60° of knee extension. Furthermore, the VM and VL of the sit-to-stand movement demonstrated less RMS EMG than those of the stand-to-sit movement from 75° to 61° of knee flexion, which was close to the initial vertical displacement phase.

초록 : 인공무릎관절의 단축범위 회전시 근력평가

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인공관절은 21세기 정형외과 발전의 주요변화들 중의 하나이다. 1997년 이래 전 세계적으로 무릎인공관절(Total Knee Arthroplasty: TKA)을 사용하는 사람들이 해마다 약 600,000명씩 증가하고 있는 추세이고 미국에서만 인공관절을 사용하고 있는 사람들이 210,000명에 달하고 있으며 그 시장은 대략 $5 billion을 넘고 있다(7). 무릎인공관절은 일상생활에서 의자에 앉았다 일어날 때 계단을 올라 갈 때 등, 무릎의 근 모멘트가 적당한 활동을 해서 무릎관절근육에 지레와 같은 작용을 하게하고, 완전한 무릎으로 정상인의 무릎과 같은 기능을 오랫동안 유지하게 한다. 이러한 목적을 달성하기 위해서는 무릎인공관절 디자인 시 정상적인 무릎 회전축(normal knee's axes of rotation)들의 정확한 위치를 파악하는 것은 중요하다. 인공관절 수술 후 무릎관절의 신전과 굴곡 운동을 하는 동안 하나의 회전축(single-axes)을 가진 하나의 회전 반경(single-radius)을 알아보는 것은 여러 축(multi-axes)으로 움직이게 된다는 다축 회전반경(multi-radius)을 분석하기에 앞서 중요한 연구이다. 따라서 본 연구에서는 무릎이 신전운동과 굴곡 운동 시 신전과 굴곡 모멘트를 만들어내는 대퇴 사두근(quadriceps muscle)과 무릎오금근 (hamstring)의 역할을 알아보았고, 또한 모멘트와 대퇴 사두근의 iEMG 형태를 파악하였다. 본 연구를 수행하기 위해 무릎인공관절 수술을 받고 1년과 3년이 지난 정상적인 생활을 하는 피검자(1년2명, 3년2명)를 대상으로 Isometric 테스트를 위한 KIN-COM III을 사용하여 60°, 30°의 무릎굴곡 측정을 하였고, Isokinetic concentric 테스트를 위해서 무릎굴곡각도의 10°-80°까지 움직임을 측정하였다. 또한 15°-75°까지의 신전운동(sit-to-stand movement)과 굴곡운동(stand-to-sit movement)을 실시하여 시간의 차이, 내전과 외전의 차이 그리고 iEMG의 차이를 알아보았다. 본 연구의 데이터는 여러 번의 실험을 통하여 가장 일반적인 수치를 사용하였다. 이 때 16-channel BTS TELEMG를 사용하여 대퇴사두근과 무릎오금근의 근육활동모양을 알아보았다. 본 연구결과는 시술 후 3년이 지나면서 TKR (Total Knee Replacement)의 대퇴 사두근 토큐가 약해지는 것으로 나타났고, iEMG 실험에서는 N-TKR (Non-Total Knee Replacement)의 대퇴 사두근이 TKR의 대퇴 사두근 보다 근 수축력이 더 크게 발휘되는 것으로 밝혀졌다. 단축회전반경의 굴곡과 신전의 10°-80°까지의 각속도는 굴곡동작이 1.19s, 신전동작이 1.68s로 나타났다. 굴곡과 신전동작에서 다리의 외전(abduction)의 각도변화는 굴곡 시 5.5°, 신전 시 5.2°로 나타났고, 내전(adduction)의 각도변화는 굴곡 시 7.2°, 신전 시 6.1°로 나타났다. 대퇴 사두근의 iEMG변화에서는 15°-60°까지 vastus medialis (VM), vastus lateralis (VL), rectus femoris (RF) 모두 굴곡동작에서 큰 값으로 나타났고, 61°-75°사이에서는 신전동작에서 iEMG가 큰 값으로 나타났다. 이와 같은 결과들은 인공관절 수술자들의 다축회전 반경을 분석하기에 앞서 중요한 선행연구가 될 것으로 생각된다.