# EMG Activities of Vastus Muscles are Related to the Shoe-heel Heights in Female Patients with Patellofemoral Pain

**Seung-Chul Chon**
Division of Occupational Therapy
Woosong University, Daejeon, 300-718, Korea

**Byung- Ki Lee**
Division of Rehabilitation Medicine
Catholic University of Korea, St. Mary's Hospital, Incheon, 403-720, Korea

**Tae-Hyung Yoon**
Division of Health Administration
Dongseo University, Busan, 617-716, Korea

***ABSTRACT***

*The aim of this study was to investigate the effect of different shoe-heel heights on the surface electromyographic (EMG) activity of vastus medialis (VM) and vastus lateralis (VL) during treadmill walking in female patients with patellofemoral pain (PFP). Nineteen women with PFP participated in this research. EMG signals were recorded from the VM and VL of both sides and were compared during the treadmill walking. The subjects walked on a treadmill wearing shoes of three different heel heights: 1 cm, 3 cm and 7 cm. Each subject walked on a treadmill for five minutes at a speed of 2 km/hour with three minutes resting intervals between consecutive trials. The data were analyzed by one-way repeated-measures analysis of variance. The results of the present study indicate that EMG data of the VM and VL of female patients with PFP did improve with an increase in the height of the shoe heel, which were statistically significant. Additionally, the EMG activity of VM increased more dramatically than that of VL associated with the task of walking with high-heeled shoes on the treadmill. This study suggests that the type of high-heeled shoes is related to the VM and VL muscle activation patterns contributing to knee joint pathologies in female patients with PFP.*

**Keywords:** *Electromyography, Patellofemoral pain, Shoe heel, Treadmill walking.*

## 1. INTRODUCTION

Patellofemoral pain (PFP) is a common musculoskeletal condition that leads to imbalance around the knee joint; and on the basis of evidence from electromyography (EMG) studies, the quadriceps muscle, in particular, has largely been considered as one of the factors contributing to biomechanical problems (Cowan et al, 2001; Edwards et al, 2008; and Karst and Willett, 1995). Because vastus medialis (VM) and vastus lateralis (VL) have antagonistic actions on the positional control of the patella, the recruitment of both the VM and VL must be biomechanically coordinated to ensure efficient knee joint function. Numerous studies have been undertaken to assess the EMG activity of VM and VL (Powers et al, 1996; Sheehy et al, 1998; and Woodall and Welsh, 1990). For example, the mechanisms underlying abnormal patellar traction include (1) patellar abnormalities, such as neuromuscular imbalance between the VM and VL; (2) connective tissue restraints, including tightness of the knee retinaculum, hamstrings, gastrocnemius, and iliotibial band; and (3) overpronation of the subtalar joint (Fagan and Delahunt, 2008; Lee et al, 2001; and Piva et al, 2009). However, the exact nature of the imbalance between the VM and VL that is the critical pathological factor underlying patellar abnormalities remains unclear.

* *Corresponding author. E-mail : toppt@naver.com*
*Manuscript received Dec. 14, 2009 ; accepted Feb. 20, 2010*

Many researchers have reported excessive lateral patellar traction to be one of the possible causes of the PFP. Thus far, exercises strengthening the VM have selectively been incorporated into the treatment regimens of patients with PFP. However, only a few studies comprising a small sample size support the claim that patients with PFP differ from healthy individuals with regard to VM and VL activation patterns (Kerrigan et al, 2005; and Mariani and Caruso, 1979). In addition, the EMG signal ratios of VM and VL have also been reported to differ during isometric, isotonic, and isokinetic muscle contraction in various positions (Boling et al, 2006; and Franklin et al, 1995).

A single biomechanical VM and VL activity or non-traumatic factor has not been identified as the primary cause of PFP. However, many such factors have been implicated in the PFP. Recent studies have suggested that other factors, such as pes planus (pronation); pes cavus (high-arched foot with supination); a large Q-angle due to tight iliotibial bands, hamstrings, and calf muscles; and weakness or tightness of the hip muscles (adductors, abductors, and external rotators) may affect the prevalence of various pathologies in the PFP (Kerrigan et al, 2005; and Syed and Davis, 2000). The various treatment approaches for this syndrome typically include the use of knee sleeves and braces, taping the knee, footwear and arch supports, and custom orthotics rather than quadriceps strengthening. Despite the above mentioned pathological factors and treatment approaches, symptomatic patellofemoral knee disorders may present with other associated complaints or variations in the presentations with respect to type of pain, pathological changes, or factors that aggravate the knee joint condition (Kerrigan et al, 2005).

Many studies have indicated that the height of the shoe heel influences muscle activation. For example, the EMG activity of both VM and VL was shown to increase with a change in the position from sitting to standing as the height of the shoe was increased (Cowan et al, 2001; and Edwards et al, 2008). High-heeled shoes have been suggested to result in an increase in the EMG activity of erector spine, tibialis anterior and rectus femoris muscle (Lee et al, 2001; Mündermann et al, 2003; and Soderberg and Knutson, 2000). High-heeled shoes may change the kinetic forces at the knee joint, followed by an increase in the mechanical load on the lower limb (Kerrigan et al, 2005). This may affect knee joint-related muscle activity and could be manifested either as an increase or decrease in the VM activity owing to the mechanisms elicited by the altered biomechanical forces at the knee joint. However, there is no consensus regarding the cause and management of PFP. A clearer discussion of these issues is important because this theory appears to be fundamental to the rationale behind the study.

Many female patients with PFP reported the frequent use of high-heeled shoes in their daily life. Since this is a possible risk factor for knee pathologies and one that can efficiently be controlled, it should be managed with attention. However, this area has received little consideration because of problems such as external cosmetic considerations. Moreover, the change in the EMG activity of VM and VL during walking with high-heeled shoes and its relation to the height of the shoe heel in patients with PFP has hardly been investigated. Therefore, this study aims to identify the effect of varying shoe-heel heights on the EMG activity of VM and VL in patients with PFP during walking on a treadmill.

## 2. METHODS

### 2.1 Subjects

A convenience sample of 19 female subjects was recruited from a university hospital. The age, height and weight of the subjects were 39.76±2.45 years, 151.23±4.17 cm and 52.25±1.25 kg, respectively. The inclusion criterion for the subjects was that they should have been diagnosed with PFP in both knee joints. Subjects with any other neurological or musculoskeletal diseases such as contractures of the lower limbs, pregnancy, and psychological problems were excluded from the study. All volunteers signed a consent form and approved verbal instructions about the procedures.

### 2.2 Randomization

Randomization was carried out by one of the investigators, who was not involved in assessment of participants. Random allocation was implemented using the conventional randomization directory process in which a random number board was used to produce one code card for each participant, who then selected a card to receive her group assignment.

### 2.3 Surface Electromyographic Recording

EMG data was not normalized because the subjects acted as their own respective controls, and all trials were performed in a main trial without changing the electrode positions (Soderberg and Knutson, 2000). The EMG data were collected simultaneously from the VM and VL of both legs using a 4-channel portable system of EMG amplifiers connected in parallel (Biometrics Data link, UK). After shaving the area and cleaning the skin with alcohol, disposable silver/silver chloride (Ag/AgCl) surface electrodes with a diameter of 20 mm each were placed on the VM and VL at standardized sites accoding to the recommendations of Gilleard et al (1998).

For each muscle, two electrodes were placed at a distance of approximately 25 mm in the direction of the muscle fibers. A reference electrode was placed over the center of the lumbosacral junction. The sampling rate was 1024 Hz. The EMG signal was amplified with an over gain of 1000 and digitized using Data log analysis software. A notch filter was used at 60 Hz, and the raw EMG data were then processed using a moving root-mean-square (RMS) window of a duration of 50 ms and converted to ASCII files for analysis (Burden et al, 2003). On the basis of the EMG signals recorded from each muscle, the RMS of individual muscles was calculated. The signals for all subjects were recorded by a single investigator. All data collection and analysis for the sessions were undertaken by the same investigator.

**2.4 Procedures**

We used commercially available high-heeled shoes that had been standardized for style, composition, and manufacturing to prevent the effect of task novelty. The ground contact area of all shoes was approximately 2 $cm^2$, which was common to all the patients. During the shoe selection, we ensured that the participants were comfortable in their respective shoe sizes or become habituated to each heel height in a familiarization session of treadmill walking over a course of two weeks before the commencement of the study. This method allowed us to overcome the methodological issues associated with the standardization of the heel height in instances where participants wore their own shoes (Kerrigan et al, 2005). Symmetrical and comfortable ambulation with a constant speed was achieved. The order of testing was determined randomly for each subject to avoid a learning effect which may change the magnitude of the activation. In case of failure to achieve it, the procedure was reattempted.

The verbal feedback from the experimenter and the visual feedback from the participant obtained by the use of a mirror placed in front of the treadmill were considered. After adequate adaptation, walking on the treadmill (H/P Cosmos, Germany) was continued for ten minutes under three heel conditions (1, 3 and 7 cm), and EMG activity data were collected over 3 minutes in the middle of the process. The speed of walking on the treadmill was set at 2 km/hour, which was comfortable for most participants, to avoid the effect of muscular fatigue on the lower limbs; a five minutes rest interval was taken between consecutive trials. The subjects repeated the task of walking on the treadmill three times under the three conditions. The measurement of EMG activity was performed in the following order: 1, 3 and 7 cm shoe-heel heights.

**2.5 Statistical Analysis**

All the data were analyzed using the statistical package for social sciences (SPSS) software version 15.0. The data have been expressed as the mean±SD. One-way repeated measures analysis of variance (ANOVA) was performed. Statistical significance was set at .05. At instances where the assumption of sphericity was violated, the Greenhouse-Geisser correction was applied. Bonferroni adjustments were used for post hoc comparisons. Intra-class correlation coefficients (ICC) were used with the average RMS of VM and VL to assess the repetitions during each heel conditions**.**

## 3. RESULTS

The EMG data of the VM and VL of both sides under the three heel conditions are presented in Table 1. The EMG data of the VM and VL of female patients with PFP improved with an increase in the height of the shoe heel, which were statistically significant (p<.05)(Table1).

Table 1. RMS data of EMG activity of VM and VL during treadmill walking. (Unit:$\mu V$)

| | Left | | Right | |
|---|---|---|---|---|
| Heelheight | VM | VL | VM | VL |
| 1cm | .31±.29* | .27±.07 | .39±.14* | .42±.23 |
| 3cm | .38±.51* | .28±.10 | .46±.29* | .46±.25 |
| 7cm | .42±.54* | .30±.15 | .48±.19* | .48±.36 |

The mean differences and 95% confidence intervals of the EMG values of the VM and VL of the left and right legs between the various shoe heel conditions are presented in Tables 2 and 3. The pair wise comparisons with Bonferroni adjustments revealed that all of the EMG activity of the VM muscle in both knee sides was statistically significant among the 1 cm, 3 cm and 7 cm heel conditions (p<.05). Specifically, there was statistically significant value of VM ($F_{(1.0,\ 18.8)}$=2.23, p=.038; $F_{(1.2,\ 21.6)}$=.59, p=.027; $F_{(1.5,\ 19.8)}$=5.43, p=.011) (Table 2) in the comparison as well as that of VM ($F_{(1.4,\ 25.6)}$=2.11, p=.045; $F_{(1.5,\ 19.6)}$=.84, p=.034; $F_{(1.4,\ 20.2)}$=6.28, p=.014) in the right side (Table 3). On the other hand, the EMG amplitude of VM between VM and VL had apparently increased with the heel height.

Table 2. Mean (95% CI) difference between conditions in average of EMG activity of VM and VL on the left side during treadmill walking. (Unit:$\mu V$)

| Comparison | VM | VL |
|---|---|---|
| 1 vs 3 cm | .034 (-.076 to .225)* | .011 (-.028 to .050) |
| 3 vs 7 cm | .054 ( .009 to .076)* | .018 ( .012 to .060) |
| 1 vs 7 cm | .108 ( .073 to .289)* | .062 ( .052 to .099) |

Table 3. Mean (95% CI) difference between conditions in average of EMG activity of VM and VL on the right side during treadmill walking. (Unit:$\mu V$)

| Comparison | VM | VL |
|---|---|---|
| 1 vs 3 cm | .021 (-.082 to .214)* | .018 (-.005 to .089) |
| 3 vs 7 cm | .066 ( .035 to .112)* | .041 ( .037 to .115) |
| 1 vs 7 cm | .086 ( .067 to .186)* | .060 ( .056 to .176) |

VM:VL EMG activity ratios were 1.01±.72 for the 1 cm heel (flat) shoes, 1.15±.93 for the 3 cm heels, and 1.41±.79 for the 7 cm heels on the left leg, and 1.13±.68 for the 1 cm heel (flat) shoes, 1.14±.62 for the 3 cm heels, and 1.22±.55 for the 7 cm heels on the right leg, as shown in Figure 1. Hence, these results indicate that improvement in the EMG activity of VM was larger than that of VL associated with the task of walking with high-heeled shoes on the treadmill. Additionally, the ICC(3,2) score ranged from .86 to .96 for VM and VL in the three heel conditions**.**

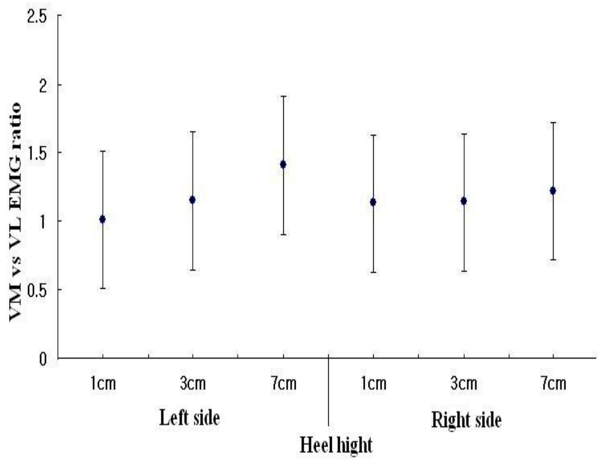

Fig. 1. VM vs VL average rectified EMG ratios during treadmill walking under three heel conditions.

## 4. DISCUSSIONS

Previous studies pertaining to the quantification of the mechanical causes related to knee pathologies have investigated the association of quadriceps muscle activity with walking with high-heeled shoes and have shown that vastus medialis and vastus lateralis activities are higher when walking with high-heeled shoes than with low-heeled ones (Edwards et al, 2008; and Souza and Gross, 1991). Many rehabilitation strategies are suggested for quadriceps strengthening in the management of PFP. In particular, training the VM through squatting exercises, working with multiple joint proprioceptive reactions, and muscular co-contraction are generally assumed to be considerably helpful (Woodall and Welsh, 1990). The recruitment of VM and VL should occur in a relatively balanced manner to ensure optimal patellar traction because VM and VL counteract each other as dynamic stabilizers of the knee joint (Cowan et al, 2001; Edwards et al, 2008; and Heintjes et al, 2003). Mechanically, the increased demand of the VM during walking on the treadmill has been attributed to the combined effects of the long and short gravitational lever arms of the quadriceps femoris muscle in normal healthy individuals. If an abnormal VM vs VL activation pattern facilitates the development of PFP, then clinicians could define correction of the VM vs VL activation pattern as a goal of rehabilitation.

Like the findings from the previous studies, our results showed that the EMG activity of the VM and VL did show an increase with the high heel shoes, as well as statistically significance in the VM muscle in both sides. The imbalance between VM and VL activation leads to an excessive lateral pull of the VL counteracted by the medial pull of the VM (Karst and Willett, 1995). Moreover, abnormal patellar traction has been reported to be one of the most important factors for PFP, which results in a change in the muscular activity around the knee joint (Heintjes et al, 2003; and Powers et al, 1996). Increased VL activity may contribute to the muscle imbalance between the VM and VL in patients with PFP. Additionally, our findings indicate that the EMG activity of VM was further improved than that of VL in the ratio of VM and VL associated with the task of walking with high-heeled shoes on the treadmill. This explains why the firing patterns of the VM and VL muscles in PFP played a role in enforcing the distribution of weight generated by the high-heeled shoes.

On the other hand, the etiology and treatment approach in the case of patients with PFP needs to be altered according to the presence of other factors such as pes planus; pes cavus; large Q-angle owing to tight iliotibial bands, hamstrings, and calf muscle; and weakness or tightness of the hip muscles. For example, tight calves resulting from walking with high-heeled shoes can (1) lead to compensatory foot pronation as in the case of tight hamstrings (Horton and Hall, 1989; and Lee et al, 2001); (2) increase the posterior force on the knee (Kerrigan et al, 2005); and (3) cause an extension lag in the load-bearing at the knee joint, which may be responsible for the alteration in the activation patterns of VM and VL (Opila-Correia, 1990).

Several limitations in our study need to be addressed, and there are areas for further improvement. Firstly, we examined only the neuromuscular system involvement in the bilateral change in the muscular parts of the quadriceps with increasing height of the shoe heel, despite the fact that such changes are generated by various combinations of tilting and rotating movements. The assessment of the change in the neuromuscular activity on the basis of these two muscles alone is difficult. Secondly, the lack of kinematic or kinetic factors is a potential limitation of our study. The use of high heels may affect the position and mechanics of the entire kinetic chain. The ankle complex and triceps surae are undoubtedly affected. We do not have data on the gastrocnemius or soleus activation patterns, and changes in the hamstring or hip flexor activity patterns is another limitation because changes occurring at the hip, trunk and ankle may explain the changes in muscle activity in the distal quadriceps muscles. Lastly, the role of timing versus magnitude of the muscle activation should also be addressed. It has been reported that in healthy subjects, there is a considerable difference in the sizes of the VM and VL muscles and a significant difference in the sizes of the left and right sides of each of these muscle types (i.e. right VM versus left VM and right VL versus left VL).

The main emphasis of our study was to identify the change in the muscle activation patterns that may be considered to be an opinion, considering the agreements with the role of VM and VL muscle balance in the majority of knee pathologies caused by high-heeled shoes. These results indicate that the function of VM played a more important role in the ratio of VM and VL and the real mechanistic rationale during treadmill walking suggested a potential effect of high-heeled shoes. It is necessary to address the questions raised by previous research before definitively concluding the etiology for PFP. The results of this study contribute towards improving the knowledge base in this field and facilitate further research.

## 5. CONCLUSION

Our findings suggest that there is an agreement with regard to the role of VM and VL muscle balance due to the several results reported after treadmill walking with high-heeled shoes. In other words, the type of high-heeled shoes worn is related to the quadriceps activity and ratio of the VM and VL in patients with PFP.

## REFERENCES

[1] M.C. Boling, L.A. Bolgla, C.G. Mattacola, T.L. Uhi and R.G. Hosey, "Outcomes of a weight-bearing rehabilitation program for patients diagnosed with patellofemoral pain syndrome", *Archives of Physical Medicine and Rehabilitation, Vol. 87, No.11,* 2006, pp. 1428-1435.

[2] A.M. Burden, M. Trew and V. Baltzopoulos, "Normalisation of gait EMGs: are-examination" *Journal* of *Electromyography and Kinesiology Vol. 13, No. 6,* 2003, pp. 519-532.

[3] S.M. Cowan, K.L Bennell, P.W. Hodges and J. McConnell, Delayed onset of electromyographic activity of vastus medialis obliquus relative to vastus lateralis in subjects with patellofemoral pain syndrome", *Archives of Physical Medicine and Rehabilitation, Vol. 82, No. 2,* 2001, pp. 183-189.

[4] L. Edwards, J. Dixon, J.R. Kent, D. Hodgson and V.J. Whittaker, "Effect of shoe heel height on vastus medialis and vastus lateralis electromyographic activity during sit to stand", *The Journal of Orthopaedic Surgery,* 2008;10:3:2.

[5] V. Fagan and E. Delahunt. "Patellofemoral pain syndrome: a review on the associated neuromuscular deficits and current treatment options", *British Journal of Sports Medicine, Vol. 42, No. 10,* 2008, pp. 489-495.

[6] M.E. Franklin, T.C. Chenier, L. Brauninger, H. Cooka and S. Harris, "Effect of positive heel inclination on posture", *Journal of Orthopaedic and Sports Physical Therapy, Vol. 21, No. 2,* 1995, pp. 94-99.

[7] W. Gilleard, J. McConnell and D. Parsons, "The effect of patellar taping on the onset of vastus medialis obliquus and vastus lateralis muscle activity in persons with patellofemoral pain", *Physical therapy, Vol. 78, No. 1,* 1998, pp. 25-32.

[8] G.M. Karst and G.M. Willett, "Onset timing of electromyographic activity in the vastus medialis oblique and vastus lateralis muscles in subjects with and without patellofemoral pain syndrome", *Physical therapy, Vol. 75, No. 9,* 1995, pp. 813-823.

[9] D.C. Kerrigan, J.L. Johansson, M.G. Bryant, J.A. Boxer, U. D. Croce and P.O. Riley, "Moderate-heeled shoes and knee joint torques relevant to the development and progression of knee osteoarthritis", *Archives of Physical Medicine and Rehabilitation, Vol. 86, No. 5,* 2005, pp. 871-875.

[10] E. Heintjes, M.Y. Berger, S.M. Bierma-Zeinstra, R.M. Bernsen, J.A. Verhaar and B.W. Koes, "Exercise therapy for patellofemoral pain syndrome", *Cochrane Database System Review,* 2003;(4):CD003472.

[11] M.G. Horton and T.L. Hall, "Quadriceps femoris muscle angle: normal values and relationships with gender and selected skeletal measures", *Physical therapy, Vol. 69, No. 11,* 1989, pp. 897-901.

[12] C.M. Lee, E.H. Jeong and A. Frievalds, "Biomechanical effects of wearing high-heeled shoes", *International Journal of Industrial Ergonomics. Vol. 28, No. 6,* 2001, pp. 321-326.

[13] P.P. Mariani and Caruso, "An electromyographic investigation of subluxation of the patella", *Journal of bone and joint surgery. British volume, Vol. 61, No. 2,* 1979, pp. 169-171.

[14] A. Mündermann, B.M. Nigg, R.N. Humble, et al. "Orthotic comfort is related to kinematics, kinetics, and EMG in recreational runners", *Medicine & Science in Sports & Exercise, Vol. 35, No. 10,* 2003, pp. 1710-1719.

[15] K.A. Opila-Correia, "Kinematics of high-heeled gait", *Archives of Physical Medicine and Rehabilitation,Vol. 71, No. 5,* 1990, pp. 304-309.

[16] S.R. Piva, G.K. Fitzgerald, J.J. Irrgang, J.M. Fritz, S. Wisniewski, G.T. McGinty, J.D. Childs, M.A. Domenech, S. Jones and A. Delitto, "Associates of physical function and pain in patients with patellofemoral pain syndrome", *Archives of Physical Medicine and Rehabilitation Vol. 90, No. 2,* 2009, pp. 285-295.

[17] C.M. Powers, R. Landel and J. Perry, "Timing and intensity of vastus muscle activity during functional activities in subjects with and without patellofemoral pain", *Physical therapy, Vol. 76, No. 9,* 1996, pp. 946-955.

[18] P. Sheehy, R.G Burdett, J.J. Irrgang, and J. VanSwearingen, "An electromyographic study of vastus medialis oblique and vastus lateralis activity while ascending and descending steps", *Journal of Orthopaedic and Sports Physical Therapy, Vol. 27, No. 6,* 1998, pp. 423-429.

[19] G.L. Soderberg and L.M. Knutson, "A guide for use and interpretation of kinesiologic electromyographic data", *Physical therapy, Vol. 80, No. 5,* 2000, pp. 485-498.

[20] D.R. Souza and M.T. Gross, "Comparison of vastus medialis obliquus: vastus lateralis muscle integrated electromyographic ratios between healthy subjects and patients with patellofemoral pain", *Physical therapy, Vol. 71, No. 4,* 1991, pp. :310-316.

[21] I.Y. Syed and B.L. Davis, "Obesity and osteoarthritis of the knee: hypotheses concerning the relationship between ground reaction forces and quadriceps fatigue in long-duration walking", *Medical Hypotheses, Vol. 54, No. 2,* 2000, pp. 182-185.

[22] W. Woodall and J. Welsh, "A biomechanical basis for rehabilitation program involving the patellofemoral joint", *Journal of Orthopaedic and Sports Physical Therapy, Vol. 11, No. 11,* 1990, pp. 535-542

**Chon Seungchul**
He received the B.S in college of health science from Yonsei university, Korea in 2000 and also received M.S degree in special education from Dankook university, Korea in 2005. Now, he has been participated in PhD program in department of physical therapy from Yonsei university. Additionally, working as a lecturer in department of occupational therapy in Woosong university. His main research interests include human biomechanics and gait & posture.

**Lee Byungki**
He received master degree in sport medicine from Korea university in 2008. Now, he attend to M.D program in medical physiology from Kyung-hee university. He work for Incheon St. Mary's Hospital, the catholic university of Korea. His main research interests in effect of breathing exercise for musculo-skeletal system disorder and effect of rehabilitation exercise in regeneration of brain.

**Yoon Taehyung**
He received the B.S. in college of health science from Yonsei university, Korea in 1998, also received M.P.H., in School of Public Health from Seoul national university, Korea in 2004, and received Ph. D. in department of health management, Graduate school from Hanyang University, Korea in 2009. Since then, he has been with the Department of Health administration, Dongseo University, Busan city, Korea. His main research interests include home-based physical therapy and long term care insurance.