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Normal range of motion of lower extremity joints in Mongolian subjects†

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Abstract: It is important to identify the normal range of motion (ROM) of the human joints for both biomechanical and clinical applications. For health care providers, including physicians and therapists, the restoration of normal ROM is a difficult task. The severity of impaired joint mobility or the postoperative rehabilitation process must be evaluated in comparison with a normal reference value. However, there is no studies have reported the ROM of the Mongolian subjects. In this study, we measured the hip, knee, and ankle joint angles using a multiple wearable inertial sensor. Ten healthy young subjects participated. The three-dimensional (3D) motion data were collected during the walking with normal speed. In our knowledge, it is first to analyze the normal ROM of the Mongolian male subjects. The collected data can be reference values for evaluating the disability of the motion and performance in rehabilitation programs.

Keywords: normal range of motion; Mongolian; wearable sensors

1. Introduction

Identification of the natural gait characteristics of people is important from both the biomechanical and clinical perspective [1]. Many diseases and injuries can impair joint mobility, which results in a decline in ROM or changes the gait characteristics. Furthermore, the abnormal gait characteristics are associated with aging and abnormal lifestyle. Joint motion varies with age and is generally more restricted in the older age group [2].

For health care providers, including physicians and therapists, the restoration of normal ROM is a difficult task. The severity of impaired joint mobility or postoperative rehabilitation process must be evaluated in comparison with normal gait patterns. These normal gait parameters have been investigated extensively in a variety of countries including the United States [3], Sweden [2], Korean and Western [1], Japanese [4], and Chinese [5]. However, there is no studies have reported the ROM of the Mongolian subjects. Furthermore, the video-based motion analysis systems cannot provide the details of the joint motions during the movements. Since the 3D joint angle measurement is an important requirement, notably in the orthopaedic and rehabilitation fields [6].

Recent developments in sensor technology allow us to precisely measure the human movements. There are several studies that have used the inertial measurement unit (IMU) sensor for analyzing the kinematics of the lower extremity during normal walking and other motions in a variety of countries [6–9]. In this study, we investigated the joints angles of the hip, knee, and ankle during the walking using wearable IMU sensors.

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2. Materials and Methods

3.1. Participant Information

Ten male subjects (age, 26.1 ± 7.8 years; height, 177 ± 7 cm; weight, 76.4 ± 17.6 kg), who had no had no musculoskeletal injuries within the past year, were recruited in this study. All subjects were recruited with informed consent from the Mongolian University of Science and Technology (MUST).

3.2. Experiment Procedure

Each subject performed three times of walking under supervision. Subjects were asked to perform the walking with normal speed to minimize the speed differences. Prior to the experiment, each participant was asked to perform several times of walking as a warm-up. The experiment was conducted in the indoor laboratory at the MUST. The subjects were wearing IMU sensors, a training suit and sports shoes. In total, 6 IMU sensors (Wearnotch, Notch Interface Inc) were used to record the right lower extremity motion during the normal walking. The sensors were attached on the chest, tummy, right thigh, shank, and foot using the straps. The IMU sensor includes 3-axis acceleration and 3-axis gyroscope with ±16 g and ±2000 °/s with a sampling rate of 100 Hz. The sensors' locations were described in Figure 1.

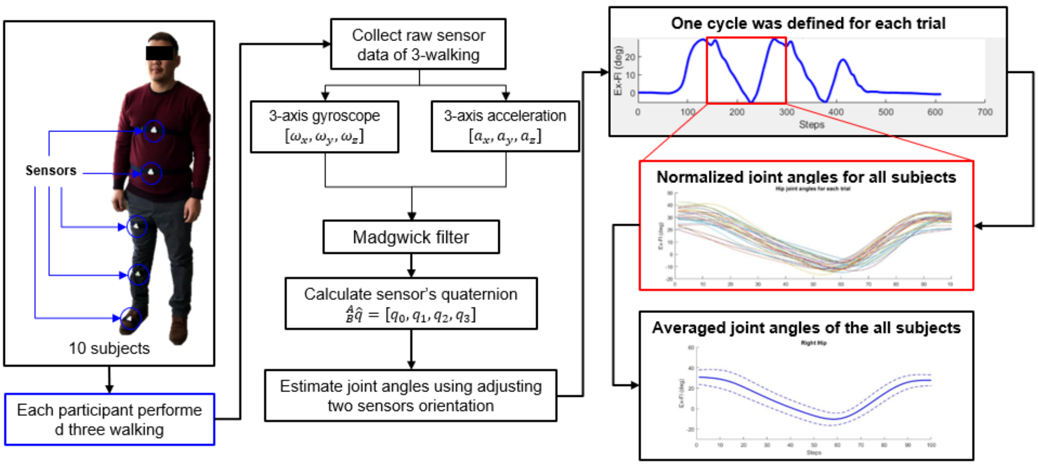

Figure 1. This is a figure. Schemes follow the same formatting.

3.3. Data Processing

At the beginning of the walking, subjects did a steady pose as a calibration. After sensor calibration, each participant performed a normal walking. The sensor's raw data sent to server computer and processed by using Matlab® R2015a (The Mathworks Inc., USA) [10]. After data processing, the quaternions of the 6 sensors were estimated using the 3-axis acceleration and 3-axis gyroscope data based on the Madgwick filter algorithm [11]. Then, the joint angles were estimated based on the orientation difference between the adjusting two sensors. The joint angles were represented as the Euler angles of the distal segment reference frame relative to the proximal segment reference frame using sensor's orientation [12]. The 3D rotations of the joints in sagittal, transverse, and coronal planes were expressed as extension-flexion (Ex-Fl), internal-external (Int-Ext) rotation, and adduction-abduction (Add-Abd), respectively (Figure 2). After calculating the 3D joint angles, the one walking cycle was defined and normalized. The start and end of the cycle were from a right heel strike to the next right heel strike.

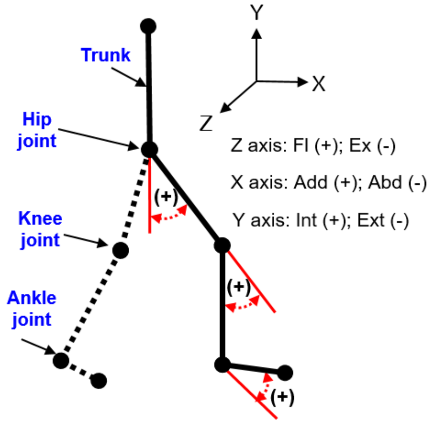

Figure 2. Joint angle definition for hip, knee and ankle joints

3. Results

3.1. Joint angles of hip, knee and ankle joint

The hip, knee, and ankle joint angles during walking are shown in Figures 3. The maximum extension-flexion angles of the hip and knee were 30.8±3.5° and 55.2±3.4°. In the ankle joint, the dorsiflexion-plantar flexion angle was 13.5±6.0°. The maximum adduction-abduction angles of the hip, knee, and ankle joints were 5.3±4.8°, 16.6±10.2°, and 10.3±5.8°. The maximum internal-external rotation angles of the hip, knee, and ankle joints were 5.5±4.5°, 7.3±10.2°, and 6.3±3.8° (Figures 3).

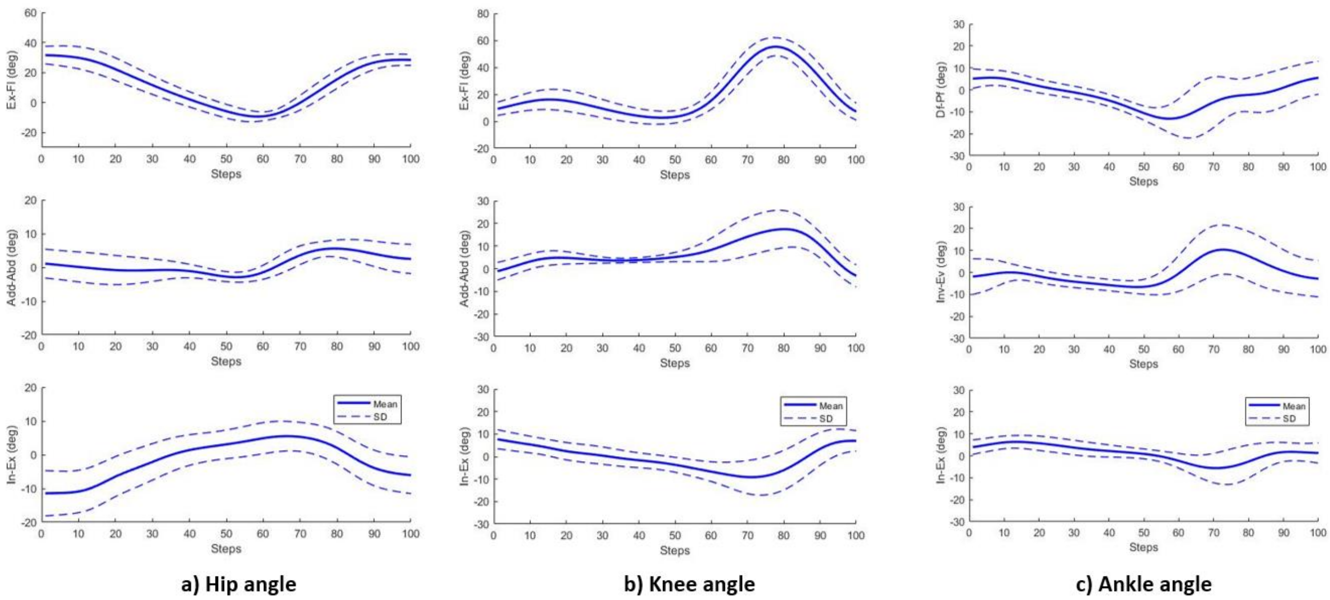

Figure 2. Joint angles of hip, knee and ankle joint

3.2. Comparison with previous studies

The maximum flexion angles of the hip, knee, and ankle joints were compared to the previous studies. The results were summarized in Table 1. The total joint angle data were similar with previous studies[1,5,13,14]. Especially, the joint angular motion of this study was similar to Asian countries. It is because of the anthropometric similarities between the Asian countries.

Throughout flexion motions, the maximum difference of hip, knee, and ankle joints between the current and the previous studies was 14.9º, 11.0º, and 14.8º, respectively. The dissimilarity may be from the use of different motion capture systems. Our study utilized the wearable motion capture system, while other studies have been used the conventional marker-based system. Of course, the difference was occurred due to the gait characteristics of different nationalities.

Table 1. Maximum flexion angles comparison with previous studies

	Hip	Knee	Ankle
Our study	30.8±5.5°	55.2±3.4°	13.5±6.0°
United States [13]	43.2°	56.7°	25.5°
Korea [1]	45.7°	58.0°	28.3°
China [5]	34.7°	66.2°	13.7°
Italy [14]	39.8°	65.3º	33.5°

4. Conclusion

In this study, we utilized the wearable IMU sensor for measuring the normal ROM of the lower extremity during the walking for Mongolians. The wearable sensor technology can be applied to both indoor and outdoor environments without any restrictions. The raw sensor data was processed using the in-house developed algorithm based on the Mahony filter. In my knowledge, it is first to analyze the 3D normal ROM of the Mongolian male subjects. But, the subjects were the only male, and a small number of the group participated. Therefore, future work will need to include a large number of subjects as well as different sex and age groups. Future work will also focus on the gait characteristics of the nomadic peoples. This study provides fundamentals of the normal gait characteristics during the walking, which can be reference values for evaluating the disability of the motion and performance in rehabilitation programs.

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Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

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Conflicts of Interest: The authors declare no conflict of interest.

References

1. Ryu, T.; Soon Choi, H.; Choi, H.; Chung, M.K. A comparison of gait characteristics between Korean and Western people for establishing Korean gait reference data. *Int. J. Ind. Ergon.* **2006**, *36*, 1023–1030, doi:10.1016/j.ergon.2006.09.013.
2. Roaas, A.; Andersson, G.B.J. Normal range of motion of the hip, knee and ankle joints in Male subjects, 30-40 years of age. *Acta Orthop.* **1982**, *53*, 205–208, doi:10.3109/17453678208992202.
3. Boone, D.C.; Azen, S.P. Normal range of motion of joints in male subjects. *J. Bone Jt. Surg. - Ser. A* **1979**, *61*, 756–759, doi:10.2106/00004623-197961050-00017.
4. Shimada, T., Takemasa, S., Kawakami, K., Inoue, Y. and Susuki, K. Normal range of motion of joints in young Japanese people. *Bull. allied Med. Sci.* **1988**, *61*, 756–759.
5. Han, S.; Cheng, G.; Xu, P. Three-dimensional lower extremity kinematics of Chinese during activities of daily living. *J. Back*

Musculoskelet. Rehabil. **2015**, *28*, 327–334, doi:10.3233/BMR-140523.

6. Favre, J.; Aissaoui, R.; Jolles, B.M.; de Guise, J.A.; Aminian, K. Functional calibration procedure for 3D knee joint angle description using inertial sensors. *J. Biomech.* **2009**, *42*, 2330–2335, doi:10.1016/j.jbiomech.2009.06.025.
7. Kim, K.J.; Agrawal, V.; Bennett, C.; Gaunaurd, I.; Feigenbaum, L.; Gailey, R. Measurement of lower limb segmental excursion using inertial sensors during single limb stance. *J. Biomech.* **2018**, *71*, 151–158, doi:10.1016/j.jbiomech.2018.01.042.
8. Tadano, S.; Takeda, R.; Miyagawa, H. Three dimensional gait analysis using wearable acceleration and gyro sensors based on quaternion calculations. *Sensors (Switzerland)* **2013**, *13*, 9321–9343, doi:10.3390/s130709321.
9. Vargas-Valencia, L.S.; Elias, A.; Rocon, E.; Bastos-Filho, T.; Frizera, A. An IMU-to-body alignment method applied to human gait analysis. *Sensors (Switzerland)* **2016**, *16*, 1–17, doi:10.3390/s16122090.
10. Choi, Y.C.; Khuyagbaatar, B.; Cheon, M.; Batbayar, T.; Lee, S.; Kim, Y.H. Kinematic Comparison of Double Poling Techniques Between National and College Level Cross-Country Skiers Using Wearable Inertial Measurement Unit Sensors. *Int. J. Precis. Eng. Manuf.* **2021**, *22*, 1105–1112, doi:10.1007/s12541-021-00511-3.
11. Madgwick S. An efficient orientation filter for inertial and inertial/magnetic sensor arrays.
12. Khuyagbaatar, B.; Purevsuren, T.; Park, W.M.; Kim, K.; Kim, Y.H. Interjoint coordination of the lower extremities in short-track speed skating. *Proc. Inst. Mech. Eng. Part H J. Eng. Med.* **2017**, *231*, doi:10.1177/0954411917719743.
13. Kadaba, M.P, Ramakrishnan, H.K, Wootten, M.E. Measurement of lower extremity kinematics during level walking. *J. Orthop. Res.* **1990**, *8*, 383–392, doi:10.1007/978-1-4471-5451-8_100.
14. Benedetti, M.G.; Catani, F.; Leardini, A.; Pignotti, E.; Giannini, S. Data management in gait analysis for clinical applications. *Clin. Biomech.* **1998**, *13*, 204–215, doi:10.1016/S0268-0033(97)00041-7.