INTRODUCTION
Due to the complexity of anatomical structures, understanding the kinematics of the cervical spine could be a paramount issue in clinic. The kinematic information could be a useful parameter to determine the level of cervical function, establish a treatment plan, and monitor the efficacy of rehabilitation. Although numerous assessment instruments, such as visual estimation, tape measure, universal goniometer, electronic digital inclinometer, cervical range of motion device and electromagnetic tracking system (ETS) had been reported as feasible and reliable methods in measuring the cervical kinematics, most investigations focused only on the cervical primary movement in the cardinal plane [1-5]. Thus, the currents methods are not enough for understanding the kinematics of the cervical spine.

Recently, more and more studies have used the terminologies such as workspace to substitute traditional kinematic measurements [6]. The workspace means the maximum motion area or volume that one or a multi-joint can move. However, no study explored the cervical workspace. Therefore, the purpose of the present study was to develop an objective and accurate method to quantify the cervical workspace based on the concept of the three-dimensional within which the cervical spine can move.

METHODS
All nineteen normal healthy volunteers (15 males and 4 females) with no previous cervical spine complaints were recruited in this study. Subject’s age ranged from 20 to 24 with a mean age of 21.4±1.1 years. In this experiment, a six-degrees-of-freedom electromagnetic tracking system (LIBERTY™, Polhemus Inc, USA) was used for recording the kinematic data. Real-time three-dimensional positions and orientations of the sensors were tracked at 120 Hz. The system consists of a transmitter and several receivers. Three receivers were used to monitor the cervical movements, which one is stylus receiver and the other two receivers are tightly affixed to top of head and processus spinosus of the seventh cervical spine body. The transmitter emitted an electromagnetic field was positioned nearby subject.

In order to describe the cervical trajectory in space precisely, the reference coordinate systems of head and thorax were constructed, respectively. First, all volunteers were asked to seat on a wooden chair to keep their thoracic spine in contact with backrest, relax their neck and looked straight ahead. Seven anatomical bony landmarks were recorded by a stylus receiver to construct the head and thorax reference coordinate systems. The reference coordinate system of head was originated from nose-bridge and made up by nose-bridge, the mid-point of chin, and protuberantia occipitalis externa; the reference coordinate system of thorax was originated from incisure jugularis and made up by processus xiphoideus, incisure jugularis, processus spinosus of the seventh cervical spine body, and processus spinosus of the eighth thoracic spine body [3]. The reference coordinate systems of head and thorax were defined as that the X-axes pointed to the right, the Y-axes pointed upward vertically and Z-axis was the cross product formed by X- and Y-axis and directed backward (Figure 1).

Figure 1: Anatomical bony landmarks and the coordinate systems of head (A, B) and thorax (C, D)

After initial measurement, all volunteers were instructed to flex slightly their cervical spine. This position is as the starting point. To obtain maximum cervical workspace, volunteers were asked to execute actively maximum motion of circumduction as far as possible at a normal velocity, and return their cervical to the starting point finally. Each movement was performed consecutively without stopping. No feedback was provided to correct the volunteer’s patterns of movements. Data from three successful trials of each volunteer were use for analysis. Each trial of movements
was collected at least five minutes apart.

The consecutive position and orientation data of the attached receivers could be recorded while performing circumduction. The receiver data from top of head and processus spinosus of the seventh cervical spine body was used to reconstruct the cervical workspace. The mathematical determination of the cervical workspace was computed using MATLAB software (Mathworks Inc., MA, USA).

In addition, to clarify the cervical length effect upon the cervical workspace, the relationship between these two factors was modeled by Pearson’s correlation coefficients. All statistical analyses were calculated using commercial statistical analysis software (SPSS 12.0, Chicago, IL).

RESULTS AND DISCUSSION

The graphical display of the cervical workspace is presented in Figure 2. The mean value (±standard deviation) of the cervical workspace is 6761.04 (1708.65) cm$^3$. A scatter plot of the cervical workspace versus the cervical length is shown in Figure 3. Unexpectedly, the findings from present study indicated that no correlation was found between the cervical workspace and cervical length ($r=0.392$, $p=0.097$). The potential factor contributed to the poor correlation between the cervical workspace and cervical length was the sample size. Another potential factor was the choice of volunteers.

Figure 2: The graphic display of cervical workspace for one subject (unit: cm)

Figure 3: The scatter plot of cervical workspace (cm$^3$) versus cervical length (cm)

Despite the fact that this study provides a new concept for assessing the kinematics of the cervical spine, some limitations of the present study should be noticed. The volunteers in the present were all young college students and the sample size was small. Thus, the results of present study did not seem to exactly reflect the cervical workspace for the general populations. Further work will focus on large number of individuals to establish a normal database. Also, patients with cervical dysfunctions will be recruited.

CONCLUSIONS

The results concluded that the application of the ETS for quantitative analysis of the cervical workspace was feasible. The finding from present study provides a new concept for understanding the kinematics of the cervical spine.

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