# The effect of walnut rolling training on hand function and corticospinal tract

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**Background:** We investigated the effect of the walnut rolling training for two weeks on the hand function and corticospinal tract (CST) in normal subjects.

**Methods:** Seventeen right-handed normal subjects performed walnut rolling training with their non-dominant (left) hand, with the right hand defined as the control side. The walnut rolling training was performed three times daily, for 30 minutes at a time, over two weeks. The Purdue Pegboard Test (PPT), tip pinch and grip strength (GS) were used evaluate the change of hand function, and diffusion tensor tractography (DTT) evaluated change of the CST and transcallosal fibers for the hand motor somatotopy.

**Results:** All of the clinical scores in terms of PPT, tip pinch and GS increased significantly in the post-training (PPT: 16.59±1.09, tip pinch: 5.03±2.18, GS: 40.61±10.99) in the left hand compared with pre-training (PPT: 14.94±1.36, tip pinch: 3.66±1.44, GS: 33.58±11.08) ($P<0.05$). By contrast, the clinical scores for the right hand did not differ significantly between pre- (PPT: 16.25±1.98, tip pinch: 5.75±2.26, GS: 37.58±14.61) and post-training (PPT: 16.97±1.67, tip pinch: 5.66±2.31, GS: 37.82±14.25). The fiber numbers (FN) of the right CST increased significantly in post-training DTT (2,123.05±529.07) compared with pre-training DTT (1,734.73±581.84) ($P<0.05$), whereas fractional anisotropy (FA) (pre-training: 0.50±0.02, post-training: 0.51±0.01) did not change significantly. Neither FA nor FN of the left CST and transcallosal fibers changed significantly from pre- (FA: 0.44±0.02, FN: 1,871.15±636.36) to post-training DTTs (FA: 0.45±0.03, FN: 1,823.84±701.14).

**Conclusions:** We demonstrated improvement of hand function and facilitation of the contralateral CST by walnut rolling training in normal subjects. Our results suggest that walnut rolling training can be used for improvement of hand function and facilitation of the contralateral CST.

**Keywords:** In-hand manipulation; diffusion tensor tractography (DTT); corticospinal tract (CST); hand function; walnut rolling training

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## Introduction

In-hand manipulation (IHM) ability is defined as the ability to move an object within a hand. It is necessary for activities of daily living, including tool use and handling small objects (1). Exner [1990] classified IHM into three skills: (I) translation: the ability to move an object from the finger to the palm and from the palm to the finger; (II) shift: the ability to move an object in a linear manner with the finger; and (III) rotation: the ability to turn an object around in the pads of the fingers and thumb (simple rotation) or turning an object from end to end (complex rotation) (1). Hand rolling using a walnut or an iron ball is a kind of IHM training that has been popular for a long time among old people in northeastern Asia. Walnut rolling training is popular for old people to prevent dementia in Korea. A few studies have demonstrated the cortical activation by ball rotation task in hand, using functional MRI (2-4). Among the above studies, one study reported that the walnut rolling task was the most effective for cortical activation compared with wooden ball rolling and hand grasp-release movements (3). However, it is unclear whether the walnut rolling training has an effect on the function of the hand and related neural tract in the brain.

The corticospinal tract (CST) is a major neural tract for motor function in the human brain, especially for fine motor activity of the hand (5-7). Therefore, the CST is assumed to be easily influenced by walnut rolling training, and examination of the CST would be important for evaluation of the effect of walnut rolling training on the brain. The most widely used methods for evaluating the state of the CST include transcranial magnetic stimulation (TMS), functional magnetic resonance imaging (fMRI), and diffusion tensor imaging (DTI) with diffusion tensor tractography (DTT). Compared to TMS and fMRI, DTT, which is derived from DTI, has a unique advantage of visualization and quantitative evaluation of the CST (8,9). Therefore, DTT is commonly used to detect changes of the CST (10,11).

In this study, we hypothesized that walnut rolling training could improve hand function and facilitate the contralateral fiber number (FN) of CST. To test our hypothesis, we investigated the effect of the walnut rolling training for two weeks on the hand function and CST in normal subjects.

## Methods

### *Subjects*

Seventeen right-handed healthy normal subjects (8 males, 9 females; mean age: 36.53±9.24 years, range: 25–55) were recruited according to the following criteria: (I) no brain lesion on conventional MRI [T1-weighted, T2-weighted, fluid attenuated inversion recovery (FLAIR), and T2-weighted gradient recall echo (GRE) images]; (II) no history of psychiatric, neurological, or physical illness; (III) right handedness as confirmed by the Edinburgh Handedness Inventory (12). The subjects for this study provided signed, informed consent, and the study protocol was approved by our Institutional Review Board (Ethical Application Ref: YUMC-2017-06-020).

### *The walnut rolling training*

Subjects performed the walnut rolling training with their non-dominant (left) hand. Subjects were allowed to pick two walnuts which suit best to their hand among walnuts with various sizes: the selected walnuts were 2.5 cm in diameter at most. They were asked to roll the walnut in the counterclockwise direction within their non-dominant hand. The walnut rolling training was performed with a steady speed (approximately 0.5 Hz) three times per day, for 30 minutes at a time, over two weeks. To ensure that each participant complied with the rules dedicating 90 minutes per day to the training, a supervisor checked whether the walnut rolling training was performed during the specified time using video telephony (first training: am 8:00 to 8:30, second training: pm 1:00 to 1:30, and third training: pm 5:00 to 5:30).

### *Clinical evaluation*

The Purdue Pegboard Test (PPT), tip pinch and grip strength (GS) were used to evaluate hand function at pre- and post-walnut rolling training. To evaluate the PPT (Lafayette instruments, model-32020), the subjects were asked to place pegs in holes as quickly as possible; the score of the PPT is the number of pegs placed in holes within 30 seconds (13-17). For the tip pinch (Jamar Hydraulic Pinch Gauge, model-J00111), the subjects were asked push with the tip of their index finger and hold the pinch gauge with thumb as forcefully as possible, the parameters of the pinch test indicates the strength of the pinch of thumb and index finger. Finally, for GS, the subjects were asked to sit on a chair in an upright position (hip joint flexed at 90° and shoulder joint in a neutral position, elbow fixed at 90° flexion, forearm in a neutral position, and wrist at 0° to 15° radial deviation), then to grasp the Jamar dynamometer (Jamar Hydraulic Hand Dynamometer, model-5030J1) with maximal strength (the score represents the GS of the hand). The reliability and validity of PPT (16), tip pinch (18) and GS (19) are well established. All of the clinical evaluations were performed three times and average values for each test were used in the statistical analysis.

### *DTT*

DTI data were acquired twice (pre- and post- walnut rolling training) using a 1.5 T Philips Gyroscan Intera system (Philips, Ltd, Best, The Netherlands) equipped with a Synergy-L Sensitivity Encoding (SENSE) head coil using a single-shot, spin-echo planar imaging pulse sequence. For each of the 32 non-collinear diffusion sensitizing gradients, 60 contiguous slices were acquired parallel to the anterior commissure-posterior commissure line. Imaging parameters were as follows: acquisition matrix =96×96, reconstructed to matrix =192×192, field of view =240 mm × 240 mm, TR =10,398 ms, TE =72 ms, parallel imaging reduction factor (SENSE factor) =2, EPI factor =59 and b =1,000 s/mm$^2$, NEX =1, thickness =2.5 mm.

#### Reconstruction of the CST

Fiber tracking was performed using the fiber assignment continuous tracking algorithm implemented within the DTI task card software (Philips Extended MR WorkSpace 2.6.3). Each DTI replication was intra-registered to the baseline “b0” images to correct for residual eddy-current image distortions and head motion effect, using a diffusion registration package (Philips Medical Systems). The CST was reconstructed using fibers passing through two regions of interest (ROIs) on the color map. The seed ROI was placed at the upper pons (portion of anterior blue color) on the color map with an axial image. The target ROI was placed at the mid pons (portion of anterior blue color) on the color map with an axial image. Termination criteria used for fiber tracking were fractional anisotropy (FA) <0.15, angle <27° (20).

#### Reconstruction of the transcallosal fiber for the hand motor somatotopy

Diffusion-weighted imaging data were analyzed using the Oxford Centre for Functional Magnetic Resonance Imaging of the Brain (FMRIB) Software Library (FSL; www.fmrib.ox.ac.uk/fsl). Affine multi-scale two-dimensional registration corrected the head motion effect and image distortion due to eddy current. Fiber tracking was performed using a probabilistic tractography method based on a multifiber model, and applied in the current study utilizing tractography routines implemented in FMRIB Diffusion (5,000 streamline samples, 0.5 mm step lengths, curvature thresholds =0.2). The transcallosal fiber (TCF) for the hand somatotopy of the primary motor cortex was identified by selection of fibers passing through both ROIs. Seed ROIs were placed on the precentral knob. A target ROI was placed on the CC on the color map (21). Out of 5,000 samples generated from the seed voxel, results for contact were visualized at a threshold for the TCF for the hand motor somatotopy of 20 streamlined through each voxel for analysis. Values of FA and FN of the reconstructed CSTs and TCF for the hand motor somatotopy were measured.

### *Statistical analysis*

Statistical analyses were performed using SPSS software (SPSS Inc. Released 2009. PASW Statistics for Windows, Version 18.0. Chicago: SPSS Inc.). The paired *t*-test was used for determination of differences in values of the DTT parameters (FA and FN) and scores of clinical evaluations (PPT, tip pinch, and GS). Pearson correlation coefficients were calculated to assess the strength of association between scores of clinical evaluations (PPT, tip pinch and GS) and DTT parameters of the CST and TCF. Null hypotheses of no difference were rejected if P values were less than 0.05.

## Results

The clinical scores of PPT, tip pinch and GS are summarized in *Table 1*. The clinical scores of PPT, tip pinch and GS increased significantly following training in the left hand compared with pre-training (P<0.05). By contrast, the clinical scores for the right hand did not differ significantly between pre- and post-training (P>0.05).

DTT parameters for the right CST, left CST, and TCF for the hand motor somatotopy are revealed in *Table 2*. FN of the right CST increased significantly in post-training DTT compared with that of pre-training DTT (P<0.05) (*Figure 1A*), whereas FA did not change significantly (P>0.05). Both FA and FN of the left CST and TCF for the hand motor somatotopy did not change significantly between pre- and post-training DTTs (P>0.05) (*Figure 1B,C*).

## Discussion

In the current study, we investigated the change of the hand function, and the CST and TCF in hand motor somatotopy resulting from two weeks’ walnut rolling training in 17 normal subjects. We found the following results: (I) PPT, tip pinch, and GS increased in the training hand (the left hand) without change in the non-training hand (the right hand); and (II) the contralateral (right) CST that innervates the walnut rolling training side (the left hand) showed

**Table 1** Clinical scores at pre- and post-walnut rolling training

| Clinical data | PPT | | Tip pinch | | GS | |
|---|---|---|---|---|---|---|
| | Right hand (control side) | Left hand (training side) | Right hand (control side) | Left hand (training side) | Right hand (control side) | Left hand (training side) |
| Pre-training | 16.25±1.98 | 14.94±1.36 | 5.75±2.26 | 3.66±1.44 | 37.58±14.61 | 33.58±11.08 |
| Post-training | 16.97±1.67 | 16.59±1.09 | 5.66±2.31 | 5.03±2.18 | 37.82±14.25 | 40.61±10.99 |
| P value | 0.08 | 0.00* | 0.64 | 0.00* | 0.72 | 0.00* |

Values: mean ± standard deviation. *, significant differences between pre- and post-walnut rolling training, P<0.05. PPT, Purdue pegboard test, GS, grip strength.

**Table 2** The parameters of diffusion tensor tractography at pre and post-walnut rolling training

| DTT parameter | CST | Pre-training | Post-training | P value |
|---|---|---|---|---|
| FA | Right CST (training side) | 0.50±0.02 | 0.51±0.01 | 0.15 |
| | Left CST (control side) | 0.51±0.01 | 0.51±0.01 | 0.20 |
| FN | Right CST (training side) | 1,734.73±581.84 | 2,123.05±529.07 | 0.00* |
| | Left CST (control side) | 1,705.45±587.37 | 1,754.57±560.17 | 0.16 |
| FA | TCF for the hand motor somatotopy | 0.44±0.02 | 0.45±0.03 | 0.32 |
| FN | | 1,871.15±636.36 | 1,823.84±701.14 | 0.60 |

Values: mean ± standard deviation. *, significant differences between pre- and post-walnut rolling training, P<0.05. FA, fractional anisotropy; FN, fiber number; CST, corticospinal tract; TCF, transcallosal fiber; DTT, diffusion tensor tractography.

increased FN without change of FA value. However, the ipsilateral (left) CST and TCF for the hand motor somatotopy did not change in FA and FN with the walnut rolling training.

In the clinical assessment for change of the hand function, PPT, tip pinch and GS increased in the training side (the left hand) by two week's walnut rolling training. The increased scores of PPT might be explained by the nature of walnut rolling, which facilitates the fine motor ability of hand. It includes individual movements of the thumb and the remaining four fingers of flexion, extension, abduction, adduction, and opposition. These results suggest that training involving finger movements like walnut rolling are effective for improving fine motor ability of the hand. For tip pinch and GS, which represent forces of the fingers and hand, rotation and holding of the walnut during walnut rolling appeared to contribute to increase these forces. Our results with regard to the change of hand function agree with studies that found a close association between the CST and fine motor ability and gross power of the hand (22-30).

In DTT parameters on pre- and post-training DTTs, only FN of the right CST that innervate the training (left) hand without change of FA value and in other neural tracts (the left CST and TCF for the hand motor somatotopy). FN of the CST indicates the existing FN of the CST (31,32). By contrast, FA value, which indicates the degree of directionality of water diffusion, represents the degree of directionality and integrity of white matter microstructures, such as axon, myelin, and microtubule (9,33). Our observation that FN of the right CST increased without change of FA value suggest that the total FN of the right CST increased with two weeks of walnut rolling training. This agrees with studies that report an association between improvement of motor function and increment of FN of the contralateral CST (34-36). No change of DTT parameters of the left CST and TCF for the hand motor somatotopy means the effect of the walnut rolling training was confined to the contralateral CST (37).

Many neuroimaging studies reported on the effects of IHM. Only a few studies reported an effect of IHM similar to the walnut rolling in this study (2-4). In 1998, Kawashima *et al.* reported increased cerebral blood flow in the primary motor area, premotor area, and cerebellum during the ball rotation task using position emission tomography in

 

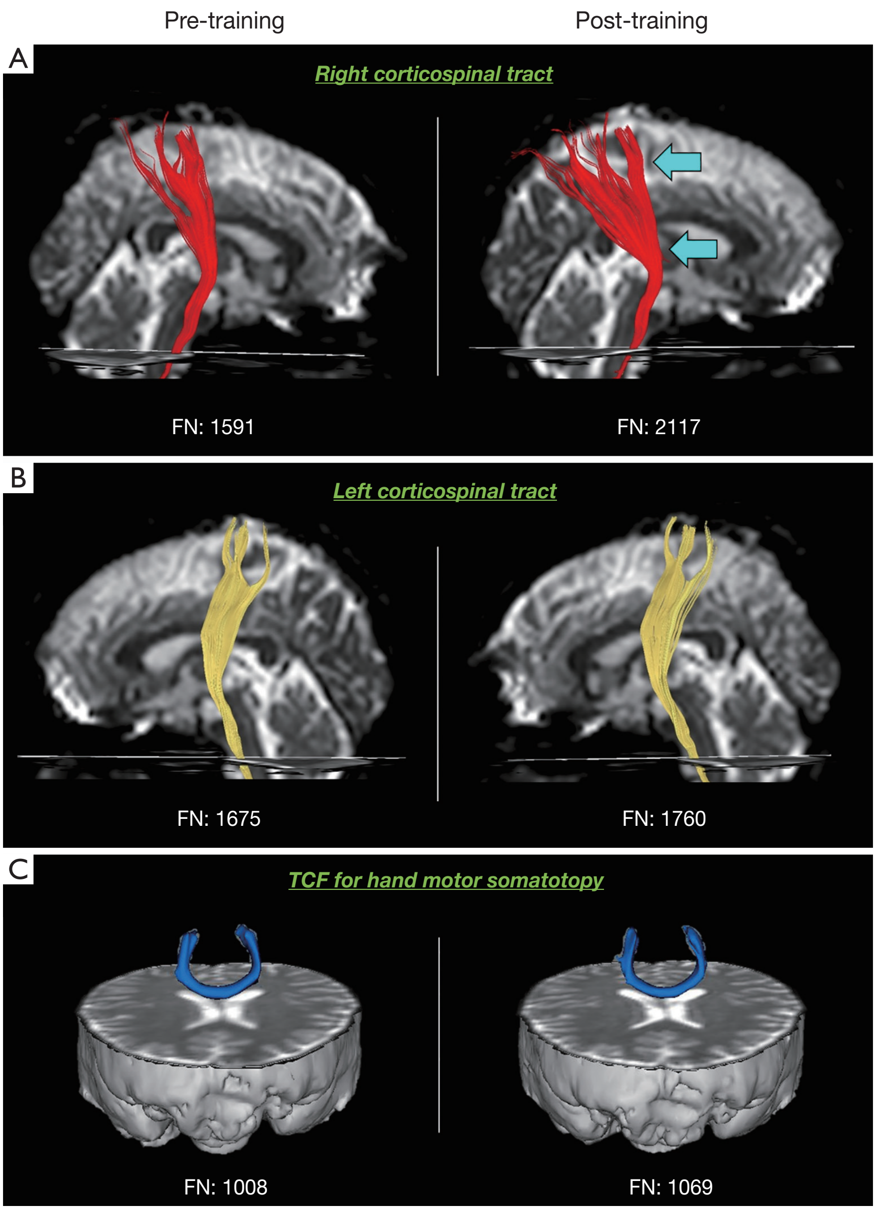


**Figure 1** The change of the neural tracts on pre- and post-walnut training diffusion tensor tractography (DTT) in a 32-year-old female subject. (A) The right corticospinal tract [CST, fiber number (FN): 2117] on the post-training DTT became thicker (arrows) compared with pre-training DTT (FN: 1591); (B,C) the left CST the transcallosal fibers for the hand motor somatotopy do not change significantly on pre- and post-training DTTs.

eight normal subjects (2). In 2006, Jang *et al.* evaluated the differences of the cortical activation by walnut rolling, wooden-ball rolling, and hand grasp-release movement using fMRI in 12 normal subjects (3). They found total activation in the cerebral cortex occurred in order of walnut rolling, wooden ball rolling, and hand grasp-release movement. In 2008, Park *et al.* investigated the difference of cortical activation during wooden ball rotation task and grasp-release movement of the hand using fMRI in 11 normal subjects (4). They found stronger activation of the primary sensorimotor cortex, premotor area, and the ipsilateral cerebellum during wooden ball rotation task compared with grasp-release movement of the hand. To the best of our knowledge, this is the first study to demonstrate an effect of walnut rolling training on the hand function and the CST on DTT in normal subjects. However, the limitations of this study should be considered. First, this study included a small number of subjects. Second, although DTI is a good anatomic imaging tool, it can produce both false positive and negative results due to the complexity and crossing fiber effect (38). Third, we used the hand opposite from the walnut rolling training hand as a control rather than recruiting a control group.

In conclusion, we demonstrated improvement of the hand function and facilitation of the contralateral CST by two weeks' walnut rolling training in normal subjects. Our results suggest that walnut rolling training can be used for improvement of hand function and facilitation of the contralateral CST for the patients with brain injury as well as normal subjects. As a result, intensive short-term IHM training (90 minutes per day during two weeks) led to some increase in hand function and facilitation of the contralateral CST. This carries important implications for sport or skill training for normal subjects and neuro-rehabilitation for patients with brain injury.

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## Footnote

*Conflicts of Interest:* The authors have no conflicts of interest to declare.

*Ethical Statement:* The study was approved by our Institutional Review Board (Ethical Application Ref: YUMC-2017-06-020) and written informed consent was obtained from all patients.

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