MRI DIFFUSION OF ROTATOR CUFF MUSCLE IN TWO DIFFERENT TYPE OF TRAINING METHODS OF STATE-LEVEL WEIGHTLIFTERS

By:

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Dissertation Submitted in Partial Fulfillment of the Requirements for Master of Medicine (Radiology)

UNIVERSITI SAINS MALAYSIA

2017

ACKNOWLEDGEMENT

First and foremost, my greatest thanks to God the Almighty for giving me patience, strength, ability and ideas for completing my dissertation. My special gratitude to my dearest husband and my parents for their perpetual support and patience. Without them, this masterpiece would not have been completed.

My most sincere thanks to my supervisor Dr Juhara Binti Haron and co-supervisor Associate Professor Dr Mohd Ezane Aziz (Lecturer Radiologists, Department of Radiology, School of Medical Sciences, Universiti Sains Malaysia, Kubang Kerian, Kelantan) for spending their precious time giving guidance and supervision. The kindness and their guidance has been the main support for me to complete this dissertation project.

I would also like to take this opportunity to convey my deepest gratitude to the following individuals for their support for their advice, guidance, comments and support during the preparation of this dissertation.

• Dr. Siti Azrin Ab Hamid, Lecturer and Statistician, Department Research and bioethic, School of Medical Sciences, Hospital University Sains Malaysia for her guidance and advice on statistic and data analysis.

• All lecturers/radiologist, Department of Radiology, School of Medical Sciences, Universiti Sains Malaysia, of whom directly or indirectly contributed their ideas and comments to the success of this study.

• Colleagues and radiology staffs of Radiology Department, HUSM

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LIST OF SYMBOLS, ABBREVIATIONS AND ACRONYMNS

ADC	Apparent Diffusion Coefficient
DTI	Diffusion Tensor Imaging
DWI	Diffusion Weighted Imaging
FA	Fractional anisotropy
FIT	Fast isokinetic training
HUSM	Hospital Universiti Sains Malaysia.
ISM	Infraspinatus muscle
MRI	Magnetic Resonance Imaging
SCM	Subscapularis muscle
SSM	Supraspinatus muscle
TMM	Teres minor muscle
TOT	Traditional isotonic training
Λ	Eigenvalues (λ 1, λ 2, λ 3)

A**BSTRACT**

MRI DIFFUSION OF ROTATOR CUFF MUSCLE IN TWO DIFFERENT TYPE OF TRAINING METHODS OF STATE-LEVEL WEIGHTLIFTERS

Objective: To compare the rotator cuff muscles changes on MRI Diffusion study between state-level weightlifter who underwent fast isokinetic training (FIT) and traditional isotonic training (TOT) exercise. **Methodology:** Gender and weight matched subjects were grouped into two types of exercises; FIT and TOT. Both groups underwent 24 sessions of training consisted of 3 distinct lifting positions. The trainings were scheduled 3 times per week for 8 weeks. MRI diffusion was conducted twice, at pre-training and 1 week post-training completion. The Fractional anisotropy (FA), Apparent Diffusion Coefficient (ADC) values and eigenvalues between two groups were evaluated. **Results:** A total of 22 subjects were enrolled but only 16 subjects completed the training programmes. Equal number of subjects (n=8) were subjected for each training programme. There were significant changes of the λ1 in supraspinatous muscle (SSM), infraspinatous muscle (ISM) and subscapularis muscle (SCM) in FIT indicate increased in muscles elongation almost in similar pattern. FA values increased in both training methods for all the muscles except supraspinatous muscle (SSM) in TOT. Among these, only FA of Subscapularis muscle (SCM) in FIT was statistically significant. **Conclusions:** Both FIT and TOT have a potential to be proposed as an additional mode of training among the experienced weightlifters to improve their performance. DTI is a good technique to evaluate muscle diffusion changes.

Keywords: *Fast isokinetic training (FIT), Traditional isotonic training (TOT), state-level weightlifter, MRI Diffusion*

ABSTRAK

KAJIAN MRI OTOT-OTOT BAHU DI ANTARA DUA JENIS LATIHAN DIKALANGAN ATLIT ANGKAT BERAT PERINGKAT NEGERI

Objektif: Untuk membandingkan perubahan terhadap otot-otot bahu melalui kajian MRI diffusi di antara latihan isokinetik pantas berbanding latihan tradisional isotonic di kalangan atlit angkat berat peringkat negeri. **Metodologi:** Melalui suaipadan jantina dan berat, peserta-peserta dibahagikan kepada dua kumpulan latihan iaitu latihan isokinetik pantas dan latihan tradisional isotonic. Kedua kumpulan menjalani 24 sessi latihan angkat berat tiga (3) posisi berlainan. Latihan ialah sebanyak tiga kali seminggu selama 8 minggu. MRI diffusi dijalankan dua kali iaitu sebelum latihan ini dijalankan dan satu lagi dalam tempoh seminggu selepas tamat tempoh latihan. **Keputusan:** Seramai 22 peserta setuju mengikuti latihan ini, tetapi hanya 16 peserta yang menamatkan pogram latihan-latihan ini. Lapan peserta (n = 8) untuk setiap jenis latihan. Hasil kajian mendapati ada hubung-kait perubahan λ1 dalam otot suprasinatous, otot infraspinatous dan otot subscapularis dalam latihan isokinetik pantas menunjukkan peningkatan otot memanjang dalam corak yang lebih kurang sama. Nilai FA meningkat di dalam kedua-dua jenis latihan kecuali otot supraspinatus di dalam TOT. Walaubagaimanapun, nilai FA oleh otot subscapularis sahaja menunjukkan ada hubung-kait. **Kesimpulan:** Kedua-dua latihan isokinetik pantas dan latihan tradisional isotonic mempunyai potensi sebagai teknik tambahan untuk latihan untuk atlit angkat berat yang berpengalaman bagi meningkatkan prestasi. Diffusion tensor imaging (DTI) merupakan sejenis teknik yang bagus untuk mengkaji perubahan diffusi dalam otot.

Kata kunci*:* *latihan isokinetik pantas, latihan tradisional isotonic, atlit angkat berat peringkat negeri, MRI diffusi*.

SECTION 1

INTRODUCTION

1.1 INTRODUCTION

The rotator cuff is a group of tendons and muscles in the shoulder, connecting the upper arm (humerus) to the shoulder blade (scapula). The rotator cuff tendons provide stability to the shoulder. The muscles that are included in the rotator cuff are Teres minor muscle (TMM), Infraspinatus muscle (ISM), Supraspinatus muscle (SSM) and Subscapularis muscle (SCM). Each muscle of the rotator cuff inserts at the scapula, and has a tendon that attaches to the humerus. Each of these muscles works in conjunction with the others to provide the harmony of motion essential for maintaining the muscular stability of the shoulders and preventing injuries.

The high prevalence of shoulder injury among elite weightlifters indicates the importance of strengthening the rotator cuff muscles. In traditional isotonic training (TOT), due to the nature of isotonic contraction, the muscular power development is only specific at the initial segment of range of motion. While for fast isokinetic training (FIT), it is capable to apply maximal resistance throughout the total range of motion, this type of training is superior to traditional weightlifting training in terms of improving power output. Despite the many advantages of eccentric training in terms of force development and muscular adaptation, researches regarding FIT are lacking.

Previous studies focused on volunteers who were not trained in resistance training. Elite athletes adapt differently to training stimulus compared to inexperienced subjects. Therefore, we recruited state level weightlifter for this study.

MRI consists of a large circle magnet. Once the body of the patient has been placed in the chamber, the MRI machine blasts sound waves at the body. These sound

waves disrupt the hydrogen molecules of the body but then they are immediately stabilised by the magnet. By using computer software, an image can be produced showing where the molecules are. In essence, the machine sends hydrogen into a frenzy then makes it return to it's original place and creates an image from the before, during and after data . MRIs are primarily used to examine the musculoskeletal system of the body. As we know, MRI are painless, requiring no incision and no exposure to radiation.

Diffusion Tensor Imaging (DTI) is an imaging technique used to identify the unique directional movement of molecules, especially water molecules, along muscle and neural tracts. DTI is increasingly applied in the detection and characterisation of skeletal muscle. This promising technique has aroused much enthusiasm and generated high expectations, because it is able to provide some specific information of skeletal muscle that is not available from other imaging modalities. Compared with conventional MRI, DTI could reconstruct the trajectories of skeletal muscle fibers. It makes it possible to non-invasively detect several physiological values (diffusion values), like fractional anisotropy (FA) and apparent diffusion coefficient (ADC), which have a great association with the muscle physiology and pathology.

Nowadays, majority of the DTI study concentrating to hamstring or muscle only. There is still lacking of research regarding rotator cuff muscle neither MRI nor DTI.

Therefore, the objective of this study was to study regarding DTI of the rotator cuff besides also study regarding any significant changes of rotator cuff muscle in the FIT compared to TOT in state-level weightlifters.

SECTION 2

LITERATURE REVIEW

2.1 DIFFUSION TENSOR IMAGING

Diffusion imaging provides quantitative information on muscle geometry, which is the main mechanical determinant of muscle performance and the effect of physical. It is a noninvasive technology that provides a full three dimensional overview of the tissue of interest. It exploits the property that the apparent diffusivity of water is greatest along the dominant muscle fiber direction. Most of the information gained by diffusion MRI is unique, in the sense that no alternative procedures exist that deliver similar insight.*(*Froeling.*et.al,*2012*)*. Diffusion weighted imaging **(**DWI) also provides qualitative and quantitative functional information concerning the microscopic movements of water at the cellular level. The signal intensity of DWI relies on the stochastic Brownian motion, or self diffusion, of water molecules at a microscopic level within tissues *(*Khoo *et a*,. 2011).

DTI has great potential to characterise physiological properties, tissue microstructure and architectural organization of skeletal muscle. It also can give several diffusion values of skeletal muscle (Xu *et al,* 2012).

Several studies have proposed the cell membrane as the main water diffusion restricting factor in the skeletal muscle cell. We sought to establish whether a particular form of exercise training (which is likely to affect only intracellular components) could affect water diffusion. Besides that, myofilaments, an intracellular component, increase in size and number as a result of physical muscle training. Skeletal muscle hypertrophy

induces an increase of endomysium or sarcoplasmic reticulum in the intracellular space, which affect water diffusion restriction (Okamoto *et al*, 2014).

Following vigorous exercise the signal from those muscle groups showing increase on T2W images. The changes in T2 signal intensity are mainly related to the changes in intra and extracellular water content of the muscle. It has been observed that after a training regime, reduced muscle bulk is used (Green *et al*, 1999).

Previous study able to show comparison between the trained and untrained athletes, MR imaging can document differences in muscle recruitment by showing obvious disparities in the location, extent, and degree of T2 signal intensity changes induced by exercise (Boutin *et.al,* 2002).

Skeletal muscle is an important tissue structure existing human body, and a quantity researches have engaged in studying the architectural structure and physiological function of the peripheral skeletal muscle. At present, many investigations relied on invasive muscle biopsy method, which has a great limitation in wide clinical application. Thus, MRI which is non-invasive and subject-specific technique,is a preferred technique to analyse the morphological and functional data of a whole skeletal muscle. Myofilaments, an intracellular component, increase in size and number as a result of physical muscle training. Skeletal muscle hypertrophy induces an increased of endomysium or sarcoplasmic reticulum in the intracellular space, which affect water diffusion restriction.*(*Okamoto *et al* 2014*).* Based on these principles, the Diffusion Tensor Imaging (DTI) can be used to assess the diffusion changes.

Therefore, the purpose of this study was to characterise prospectively the changes in DTI values of rotator cuff muscle resulting from the FIT and TOT.

2.2 ISOKINETIC AND ISOTONIC TRAINING

Isokinetic training is a type of training performed using a specialised apparatus that provides variable resistance to a movement, so that no matter how much effort is exerted, the movement takes place at a constant speed. It is capable to apply maximal resistance throughout the total range of motions, this type of training is superior to traditional weightlifting training in terms of improving power output. Isokinetic method of training can be used to restore the imbalances of the rotator cuff muscles group. Rotator cuff muscles are important to stabilise the shoulder joint during lifting. Malliou *et.al* 2003, noted that isokinetic is the most effective type of training in changing the ratio of the rotator cuff muscles as compared to multi joint dynamic resistance training and dumbbell isotonic training which further reduce the risk of shoulder injury when performing repetitive lifts.

For isotonic exercise, it uses fixed weight but the candidates can decide how fast they want to lift it. So, they can decide the speed, but the weight (resistance) remain constants. In traditional isotonic training (TOT), due to the nature of isotonic contraction, the muscular power development is only specific at the initial segment of range of motion. Typical weight lifting training involved isotonic muscle contraction of lifting a free weight such as dumbbell and barbell. Examples of this type of training are biceps curl and triceps curl. An isotonic muscle contraction induced the greatest resistance only at the weakest mechanical points of the range of motion (ROM) of the conducted movement. In addition, the resistance remains constant throughout the range of motion with varied angular velocity of the involved joint (Kovaleski *et. al*, 1995; Smith & Melton, 1981). However, the main problem with weight lifting is the inability to maintain the angular velocity towards the end of concentric phase in which the bar

velocity slows down towards the end of range of motion. Thus, power development may be improved only at the initial segment of the ROM. (Kraemer & Ratamess, 2004).

Therefore, this study aimed to compare the FA, ADC and eigenvalues of rotator cuff muscle on MRI DTI among state-level weightlifters who underwent FIT and TOT programme.

SECTION 3

OBJECTIVE OF THE STUDY

3.1 GENERAL OBJECTIVE

To compare the Diffusion Tensor Imaging (DTI) parameters changes of rotator cuff muscle in weightlifters using MRI.

3.2 SPECIFIC OBJECTIVES

1. To compare the mean Fractional anisotropy (FA), Apparent diffusion coefficient (ADC) values and three eigenvalues lambda of rotator cuff muscle between pre-training and within 1week after completion of training in fast isokinetic training (FIT) of state-level weightlifters.

2. To compare the mean Fractional anisotropy (FA), Apparent diffusion coefficient (ADC) values and three eigenvalues lambda of rotator cuff muscle between pre-training and within 1week after completion of training in traditional isotonic training (TOT) of state-level weightlifters.

3. To compare the mean Fractional anisotropy (FA), Apparent diffusion coefficient (ADC) values and three eigenvalues lambda changes of rotator cuff muscle between pre-training and within 1week after completion of training in fast isokinetic training (FIT) and traditional isotonic training (TOT) of state-level weightlifters.

SECTION 4

MANUSCRIPT

4.1 TITLE PAGE

Title : Comparison of Diffusion Tensor Imaging (DTI) parameters of rotator cuff muscle between fast isokinetic training and traditional isotonic training methods among state-level weightlifters

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Disclosure of Funding: This study was supported by Universiti Sains Malaysia Research University Grant Scheme no: 1001/PPSP/812209.

4.2 ABSTRACT

Objective: To compare the rotator cuff muscles changes on MRI Diffusion study between state-level weightlifter who underwent fast isokinetic training (FIT) and traditional isotonic training (TOT) exercise. **Methodology:** Gender and weight matched subjects were grouped into two types of exercises; FIT and TOT. Both groups underwent 24 sessions of training consisted of 3 district lifting position. The trainings were scheduled 3 times per week for 8 weeks. MRI diffusion was conducted twice, at pre-training and 1 week post-training completion. The FA, ADC values and eigenvalues between two groups were evaluated. **Results:** A total of 22 subjects were enrolled but only 16 subjects completed the training programmes. Equal number of subjects (n=8) were subjected for each training programme. There were significant changes of the λ1 in supraspinatous muscle (SSM), infraspinatous muscle (ISM) and subscapularis muscle (SCM) in FIT indicate increased in muscles elongation almost in similar patern. Fractional anisotropy (FA) values increased in both training methods for all the muscles except supraspinatous muscle (SSM) in TOT. Among these, only FA of Subscapularis muscle (SCM) in FIT was statistically significant. **Conclusions:** Both FIT and TOT have a potential to be proposed as an additional mode of training among the experienced weightlifters to improve their performance. DTI is a good technique to evaluate muscle diffusion changes.

Keywords: *Fast isokinetic training (FIT), Traditional isotonic training (TOT), state-level weightlifter, MRI Diffusion*

4.3 INTRODUCTION

The high prevalence of shoulder injury among elite weightlifters indicates the importance of strengthening of the rotator cuff muscles.The rotator cuff is a group of tendons and muscles in the shoulder, connecting the upper arm (humerus) to the shoulder blade (scapula). Each muscle of the rotator cuff inserts at the scapula, and has a tendon that attaches to the humerus. Each of these muscles works in conjunction with the others to provide the harmony of motion essential for maintaining the muscular stability of the shoulders and preventing injuries.

Isokinetic training is a type of training performed using a specialised apparatus that provides variable resistance to a movement, so that no matter how much effort is exerted, the movement takes place at a constant speed. It is capable to apply maximal resistance throughout the total range of motions, this type of training is superior to traditional weightlifting training in terms of improving power output. Isokinetic method of training can be used to restore the imbalances of the rotator cuff muscles group. Rotator cuff muscles are important to stabilise the shoulder joint during lifting. Malliou *et.al* 2003, noted that isokinetic is the most effective type of training in changing the ratio of the rotator cuff muscles as compared to multi joint dynamic resistance training and dumbbell isotonic training which further reduce the risk of shoulder injury when performing repetitive lifts.

For isotonic exercise, it uses fixed weight but the candidates can decide how fast they want to lift it. So, they can decide the speed, but the weight (resistance) remain constants. In traditional isotonic training (TOT), due to the nature of isotonic contraction, the muscular power development is only specific at the initial segment of range of motion. Typical weight lifting training involved isotonic muscle contraction of lifting a free weight such as dumbbell and barbell. Examples of this type of training are

biceps curl and triceps curl. An isotonic muscle contraction induced the greatest resistance only at the weakest mechanical points of the range of motion (ROM) of the conducted movement. In addition, the resistance remains constant throughout the range of motion with varied angular velocity of the involved joint (Kovaleski *et. al*, 1995; Smith & Melton, 1981). However, the main problem with weight lifting is the inability to maintain the angular velocity towards the end of concentric phase in which the bar velocity slows down towards the end of range of motion. Thus, power development may be improved only at the initial segment of the ROM. (Kraemer & Ratamess, 2004).

Despite many advantages of isokinetic training in terms of force development and muscular adaptation, there are lacking of researches in fast isokinetic training (FIT). To date, no studies have been carried out to compare the effects of FIT versus TOT on rotator cuff muscle among elite weightlifters. Previous studies focused on the volunteers who were not trained in resistance training. The athletes, person who is proficient in sports and other forms of physical exercise adapt differently to training stimulus compared to inexperienced subjects. Therefore, the state level weightlifters were choosen in our study.

Skeletal muscle is an important tissue structure existing in human body, and a quantity researches have engaged in studying the architectural structure and physiological function of the peripheral skeletal muscle. At present, many investigations relied on invasive muscle biopsy method, which has a great limitation in wide clinical application. Thus, MRI which is non-invasive and subject-specific technique,is a preferred technique to analyse the morphological and functional data of a whole skeletal muscle. Myofilaments, an intracellular component, increase in size and number as a result of physical muscle training. Skeletal muscle hypertrophy induces an increased of endomysium or sarcoplasmic reticulum in the intracellular space, which affect water

diffusion restriction.*(*Okamoto *et al* 2014*)*. Based on these principles, the Diffusion Tensor Imaging (DTI) can be used to assess the diffusion changes.

DTI provides quantitative information on muscle geometry, which is the main mechanical determinant of muscle performance and the effect of physical activity. It is a non-invasive technology that provides a full three dimensional overview of the tissue of interest. It exploits the property that the apparent diffusivity of water is greatest along the dominant muscle fiber direction. Most of the information gained by DTI is unique, in the sense that no alternative procedures exist that deliver similar insights (Froeling.*et.al*, 2012). DTI also provides qualitative and quantitative functional information concerning the microscopic movements of water at the cellular level. The signal intensity of DTI relies on the stochastic Brownian motion or self diffusion of water molecules at a microscopic level within tissues.(Khoo *et al,* 2011). DTI has great potential to characterise physiological properties, tissue microstructure and architectural organisation of skeletal muscle. It also can give several diffusion values of skeletal muscle.(Xu *et al*, 2012).

Most studies have suggested that the main diffusion restricting factor is the cell membrane, given the reported correlations between DTI eigenvalues (λ) and changes in the size and shape of myocytes with age, contraction and passive shortening/stretching. In particular, in human muscle it has been suggested that changes in lambda 1(λ1) reflect change in the long axis of the myocytes, while lambda 2 and lambda3 (λ2 and λ3) reflects their width and depth respectively (short axis).

The diffusion of water in tissue is influenced by physical barriers (e.g., cellular membranes and cellular constituents). Therefore, an effective diffusivity is measured that is usually called the apparent diffusion coefficient (ADC) which is lower than the free diffusion coefficient. For tissues with fiber-like structure, such as skeletal muscle,

the diffusion is more hindered perpendicular to the fibers than along the fibers. Therefore, in these tissues the diffusion is anisotropic, with typical values of 2.2 x10−3 mm2 ·s−1 parallel to human muscle fibers and 1.3 x10−3 mm2 ·s−1 perpendicular to the fibers. The anisotropy of the diffusion can be described by the fractional anisotropy (FA) which measures the fraction of the diffusion tensor that can be ascribed to anisotropic diffusion. (Anneriet et.al, 2007).

Therefore, this study aimed to compare the FA, ADC and eigenvalues of rotator cuff muscle on MRI DTI among state-level weightlifters who underwent FIT and TOT programme.

4.4 METHODOLOGY

This study was a randomised control trial, matched parallel study (gender and weight). The state-level weight lifters either males or females, between age 10 and 20 years old were voluntarily recruited through Majlis Sukan Negeri Kelantan. These groups are the athletes that were trained under Majlis Sukan Negeri Kelantan for weightlifter with a minimum 2 years experience in training. Those with history of shoulder injury or evidence of shoulder injury on MRI were excluded. Subjects who failed to complete a minimum of 85% of training loads during the intervention period were dropped from this study.

They were randomly put in two groups, fast isokinetic training (FIT) and traditional isotonic training (TOT). The randomisation was executed following software computerised system to determine the sequence of experiments among the participants. As detailed logistic preparation needs to be carried out beforehand, the study was not blinded to the researcher and participants.

The ethical approval was obtained from Human Research Ethics Committee of Universiti Sains Malaysia Research Ethics Committee of Universiti Sains Malaysia (JEPem USM Code USMKK/PPP/JEPeM/14110457) which complies with the Declaration of Helsinki.The amendment was approved on 30th November 2015.

4.4.1 Operational Definition

1. **State-level weightlifter**: athletes whom are trained in sport of lifting barbells of specified weights in a prescribed manner for competition.
2. **Fast isokinetic training programme**: The fast isokinetic group with 24 training sessions (three times per week for eight weeks).
3. **Traditional isotonic training programme:** The control isotonic group with 24 training sessions (three times per week for eight weeks)
4. **Diffusion tensor imaging (DTI)**: a form of MR imaging based upon the diffusion of water molecules within a voxel. Diffusion weighted imaging is based upon the random Brownian motion of water molecules within the voxel. Diffusion of water inside a voxel of muscle tissue, for example, is hindered primarily by cell membrane boundaries. The greater the cellularity, the greater the diffusion restriction.
5. **Apparent diffusion coefficient (ADC)**: ADC measures the magnitude of diffusion (of water molecules) within tissue. The measurement are recorded for a given region of interest (ROI) on the ADC map. An ADC of tissue is expressed in units of mm^2/sec. There is no unanimity regarding the boundaries of the range of normal diffusion, but ADC values less than 1.0 to 1.1 x 10^{-3} mm^2/sec are generally acknowledged in as indicating restriction.
6. **Fractional anisotropy (FA)**: a scalar value between zero and one that describes the degree of anisotropy of a diffusion process. A value of zero means that diffusion is isotropic, i.e. it is unrestricted (or equally restricted) in all directions. A value of one means that diffusion occurs only along one axis and is fully

restricted along all other directions. FA is a measure often used in diffusion imaging where it is thought to reflect fiber density.

7. **Three eigenvalues**: describe magnitude of the diffusion cofficient in three orthogonal direction. The long one pointing along the muscle direction will be λ_1 and the two small axes λ_2 and λ_3 will measures width and depth respectively.

4.4.2 Training Programme

The FIT group had their training at the Sport science centre, University Sains Malaysia., while, the TOT group trained at Majlis Sukan Negeri Kelantan Gymnasium.The training was conducted for 8 weeks between August and September 2015. Both training groups had their training sessions three times per week. The isokinetic training was applied using an isokinetic dynamometer (Multi-joint System Biodex Pro, Shirley, NY, U.S.A) as in Figure 4. All participants completed one set of 12 reciprocal internal and external shoulder rotation, in concentric mode after the pre-test. The next training program commenced following at least three days of recovery.

For each training session, 10 minutes of warm-up and stretching emphasising on the shoulder was performed by each participant followed by a minute of active rest. The participant performed a proper shoulder stretching and ice pack was applied on the shoulder for 10-15 minutes to reduce muscle soreness. The dynamometer was calibrated with known weight before each training session. A correction for the mass of the limb and lever arm system was made on all torque curves. The preparation of participant on the dynamometer has closely followed the manufacturer's manual to ensure safety of the participants.

The candidates had to pass through a total of 24 sessions of trainings;

- For the first eight sessions, participants were trained in a sitting position with 45 ° shoulder abduction. This position was similar to the testing position, where the scapular was positioned so that equal distribution of external rotators and internal rotators can be assessed. The angular velocity was set at 120 °.s^{-1}, with 12-15 repetitions for two sets.

- For the ninth to sixteenth sessions, the sitting position with 90 ° of shoulder abduction was selected. The angular velocity applied was 240 °.s^{-1} with 10-12 repetitions for three sets.

- For the seventeenth to twenty forthsessions, the diagonal standing position was utilised. The angular velocity used was 360 °.sec^{-1} with 8-10 repetitions for four sets.

Progressive load (in terms of number of sets and repetitions in each set) of training was completed in eight weeks. Each training session took approximately one hour including the warm up and stretching.

The same lifting position was applied by the TOT group. The control group used a similar dumbbell weight throughout the duration of training program.The same body position was applied by the TOT group using a dumbbell. The dumbbell of 5kg weight was used in this training program for all male participants while 3kg dumbbell was provided for female participants. The angular velocity was not fixed in TOT group.

4.4.3 MRI Data Acquisition

The 3 Tesla Philips Achieva MR (Netherland) scanner 2.6.3.5 software was used to perform the DTI of rotator cuff muscles pre- and post- training. Fractional anisothrophy (FA), apparent diffusion coefficient (ADC) and the three eigenvalues lambda were measured in the rotator cuff muscles : subscapularis, supraspinatous, infraspinatous and teres minor muscles.

The 16-channel sensitivity encoding (SENSE) body coil (45 × 30 cm for parallel imaging) was wrapped around the right shoulder. DTI parameters were choosen based on previously published descriptions of lower leg muscle DTI scans. DTI were acquired using a single-shot spin-echo echo planar imaging (EPI) sequence with the following

parameters: b values of 0 and 400 s/mm2, field of view (FOV) 240(mm), rectangular FOV 100%, matrix size 96 × 94, slice thickness 2 mm without gap, internal number of slices 55, TR = 6323 ms, TE = 72 ms, SENSE factor 2, number of motion probing gradient (MPG) directions 6, number of excitations 6, and total scan time 3 min 41 s (Figure 1).

The center of the scan range was positioned at the Y shape scapula generating on the sagittal oblique image. A screen shot of a scout image of the rotator cuff muscle was used to identify the same position in the second scan. The sagittal oblique T1-fast field echo (FFE) images for anatomical mapping was acquired using the following parameters: matrix size 284× 210, slice thickness 3 mm, number of slices 30, TR = 500 ms, TE = 20 ms, and total scan time 3 min 34 s.

Image processing was performed using Philips Extended MR Workspace 2.6.3.5 software. The ADC, FA, three eigenvalues measurements are recorded for a given region by Reconstruction 3D structure using DTI-based fiber tracking (Figure 2 and 3). For eigenvalues, three measurement are taken at centre of the each muscle and the average are takens.

4.4.4 Statistical Analysis

Quantitative data were analysed using Microsoft® Office Excel and Statistical Product and Service Solutions (SPSS) for Windows, SPSS Inc.©(version18, SPSS Inc., Chicago, IL,USA). Continuous variables were expressed as mean ± S.D or median (interquartile range, IQR) and categorical variables as percentages.

Normality of data distribution was checked with Shapiro-Wilk test of normality. Paired-sample t-test was applied to evaluate the interactions within groups and Kruskal-

Wallis test for evaluation between the groups. The accepted level of significance was set at $p<0.05$.

4.5 RESULTS

A total of 22 subjects, between age 13 and 20 years old were enrolled in the study, but only 16 subjects completed the intervention programmes, given a dropout rate of 27%. Six participants were dropped out due to personal problem and non-compliance to the experimental program. The subjects were assigned into two different intervention programmes i.e. fast isokinetic training (FIT) (n=8) and traditional isotonic training (TOT) (n=8).Demographic data of the participant program is shown in Table 1. The mean for age is 14.13 (SD : 1.458) years old for FIT and 14.38 (1.768) years old for TOT. The mean for BMI is 27.66 (6.26) for FIT and 22.66 (2.73) for TOT. While the mean of height is 1.59m (0.07) for FIT and 1.59m (0.10) for TOT. The mean of weight is 70.83(19.63)kg for FIT and 57.95 (12.14)kg for TOT.

Table 2 shows comparison of DTI parameters in the rotator-cuff muscles before and after FIT. There was significant increased in the value of $\lambda 1$ of SSM, $\lambda 1$ and $\lambda 2$ of ISM and FA and $\lambda 1$ of SCM. For TMM, all parameters showed increments in value except ADC. However, these decrement was not statistically significant.

Table 3 shows comparison of DTI parameters in the rotator-cuff muscles before and after TOT. There was significant increased in the mean value of $\lambda 1$ of ISM. Significant reduction in the mean value of ADC of ISM, SCM and TMM were noted.

The changes of DTI parameters between two different types of training are shown in Table 4. Significant difference ($p<0.05$) was found in ADC values of ISM between the two different types of trainings, whereby the ADC values of subjects underwent TOT were higher than that of the subjects underwent FIT.

4.6 DISCUSSION

The use of Diffusion tensor magnetic resonance imaging (DTI) in detection and characterisation of skeletal muscle is increasing, because it provides some specific information of skeletal muscle that is not available from other imaging modalities. Unlike conventional MRI, DTI reconstructs the trajectories of skeletal muscle fibers and non-invasively detects several physiological values (diffusion values), like fractional anisotropy (FA) and apparent diffusion coefficient (ADC). These have great association with the muscle physiology and pathology *(*Xu *et.al* 2012*).*

Studies had demonstrated that, anatomically the first eigenvalue (λ1) represents the diffusion along the main direction of muscle fiber. In addition, it has been suggested that the second (λ2) and the third (λ3) eigenvalue could represent the diffusion of water within the endomysium perpendicular to the long axes of the muscle fibers and within the cross-section of a muscle fiber, respectively. As previous study by Deux *et al.* (2008) and Craig *et al.* (2004) also agree for these. Our study also shows there were differences that exist between the three eigenvalues as $\lambda 1 > \lambda 2 > \lambda 3$. These can seen in both types of training. The large reduction of λ2 and λ3 relative to λ1 suggests that there is specific structural information that can be obtained from these values. It implies the presence of an architectural hierarchy in skeletal muscle. These also supported by previous study that showed similar findings (Damon *et al.* 2002; Tseng *et al.* 2003).

Our study showed that most of the muscles of the rotator cuff show increased in eigenvalues post-training compare to pre-training in both type of trainings except for λ2 of Teres minor muscle (TMM) in TOT. These results were consistent with study by Okamoto *et.al* (2014) which also got increased in both long and short axes of the muscle post-training. The increment of these eigenvalues indicating increased muscle fibers in long axis and short axis suggestive of increased muscle strength. A study by Hyeyoung

et.al (2014) also shows significant rotator cuff muscle strength after 8weeks specific physical training.

The values were significant for λ1 in SSM, ISM and SCM in FIT. These suggestive of significant increasment muscle length or long axis in SSM, ISM and SCM for FIT. While in TOT only the λ1 of ISM was significant. In view of more significant results of muscle lengthening changes in FIT compared to TOT, these results suggested that the long axis of the muscles are more increased in FIT compared to TOT.

For λ2 and λ3, they showed increament values post-training in all muscles for FIT but only λ2 in ISM showed statistically significant. While for TOT, all λ2 and λ3 shows increament values also post-training except for λ2 in TMM. Only λ3 in ISM of TOT showed statistically significant. These results are assumed to be a consequence of insufficient sampling along the short axis of the muscle fibers. Craig et al.(2004).

The function of supraspinatous muscle (SSM) is for initiate abduction, infraspinatous muscle (ISM) and teres minor muscle (TMM) are for external rotation, while the subscapularis (SCM) is for internal rotation. More significant values in ISM likely due to these training are more effective to external rotation of shoulder compared to internal rotation. However, no significant values seen in TMM which is also the contributing muscle for external rotation. We speculate these likely due to location of teres minor which is below the ISM anatomically causing overlapping of these muscle at the level of measurement.

From our study, it was noted that the FA values are increased in both training methods for all of the muscles except SSM in TOT. However, only FA of SCM in FIT was significant. As more recently, Xu (2012) investigated the effect of active contraction using DTI and concluded that the higher FA, λ1 and λ2 values of muscles at

contraction presumably reflect microscopic morphological changes of the diffusion-restricting factor, focal temperature, and perfusion.

According to Anders et.al (2002), in exercising skeletal muscles, the ADC values are increased, presumed to reflect increased water motion, predominantly in the extracellular compartment. Furthermore, thermal storage and neurohumoral activity in active muscle also the contributings factor that causing increase of ADC values. From our study, the ADC values are increase in SSM and ISM in FIT post-training. While, the others muscle in FIT and all muscles in TOT shows reduced post-training. Among of these, ISM, SCM and TMM showed significant reduction in TOT. Therefore, we speculate increase in ADC values in SSM and ISM in FIT post-training likely due to more involvement of these muscles during training in FIT.

However, there are contradiction opinion from others study by Anneriet(2007) that muscle injury (muscle tear or intramuscular hematoma injury) results in a higher ADC, lower FA, and a disorganized fiber structure with abnormal findings in T2W sequence. ADC value increament indicates increased in intracellular water, muscle hypertrophy or inflammation. These also supported by previous study Xu (2012). In our study, eventhough there is increament in ADC value for SSM and ISM of the FIT group post-training, absence of abnormal signal intensity on T1W1 or T2WI and pain exclude injury. Therefore, these changes likely due to hypertrophy of the muscle cells with cellular constituents.

In overall, comparison of median changes diffusion values in between FIT and TOT shows that, significant difference ($p<0.05$) were only found in ADC values of infraspinatous muscle between the two different types of trainings, whereby the values were higher in TOT compared to the subjects underwent FIT. It is the only one factor in one muscle is significant in between these two. The small sample size most likely the