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Mini Review

A Novel Skeletal Muscle Assessment Using q-space Diffusion MRI

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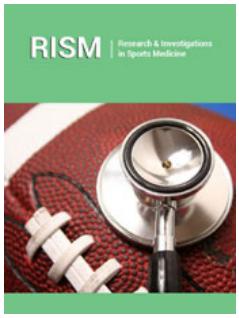

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Introduction

A novel MRI technique such as Q-Space Imaging (QSI) was first proposed by Callaghan and Cory in 1990 [1,2]. Initially, QSI was reported for the study of porous materials in the NMR world. This QSI enabled the acquisition of structural information at the micro size. Soon, QSI was also applied to living organisms, and numerous reports were made on cell deformation caused by brain diseases [3,4], shape evaluation of red blood cells [5,6], and so on.

What is QSI? A new MR imaging method? Some of you may be wondering, "What is QSI? For this reason, we will briefly describe QSI. First, QSI is not a new imaging method but an analysis method. The data is acquired by varying the b-value setting of Diffusion Weighted Imaging (DWI), which is currently indispensable in clinical practice. The QSI is an imaging method that analyzes this data using the Fourier transform. Next, what is the difference between DWI and QSI? DWI is an imaging method that reflects the diffusion phenomenon of water molecules. This diffusion is an imaging method applicable to water molecules that diffuse freely in a wide range of fluids. However, in living organisms, there are few freely diffusing tissues, and most tissues are considered to have restricted diffusion. It is often hypothesized that multiple compartments exist under restricted diffusion [7,8]. The compartmental model is very complicated, and the interpretation of diffusion in vivo is complex, and QSI is a method to analyze the limiting diffusion in biological tissues while avoiding this complex model.

In this paper, I have explained what kind of information QSI the potential must provide in the skeletal muscle field and how it will develop in the future.

Possibility of Skeletal Muscle Evaluation by q-space imaging

As mentioned above, QSI can analyze structural information in living organisms. Myofibers are cylindrical cells with a diameter of 10 to 100μm and a length of about 1cm. This aggregate is considered to be skeletal muscle. QSI can calculate and evaluate values that reflect structural information in the diameter direction.

Differentiation of diseases

Skeletal muscle diseases are divided into myopathies (myopathy), which are caused by the muscle itself and result in muscle atrophy or weakened contractility, and neuropathies

(neuropathy), which are caused by the peripheral nerves connecting the muscle. There are three approaches to differentiate between these two types of diseases: 1) by symptoms, 2) by examination, and 3) by pathology. QSI has the ability to combine 2) examination and 3) pathology. QSI is similar to a conventional MRI scan and has the potential to provide structural information similar to pathology. One of the information that can be obtained in pathology is the size of myocytes (diameter). It is possible that this information can be obtained with an MRI scan. In normal muscle, there is no difference in diameter, but in myopathic muscle disease, the space between myofibers is wide and open, and connective tissue increases, resulting in a difference in diameter. On the other hand, in neurogenic diseases, fibers with small diameters that have undergone denervation are grouped together, resulting in the so-called "group atrophy. Evaluation of these changes in myocyte diameter by QSI may provide a new approach to distinguish muscle diseases. While muscle biopsy is an invasive test, QSI is noninvasive and has the potential to be a promising test for the sole purpose of evaluating cell structure.

Functional evaluation

Muscle fibers can be broadly classified into two types: fast-twitch muscle fibers and slow-twitch muscle fibers. They can be classified into two types: fast-twitch muscle fibers and slow-twitch muscle fibers. Fast muscle fibers are said to be sprinter-type muscle fibers with high muscle contraction speed and high torque but low stamina. On the other hand, slow muscle fibers are said to be marathon-type muscle fibers that have stamina in place of slow muscle contraction speed and low torque. Other differences exist between the two types in myofiber diameter, mitochondrial capacity, and capillary density. Of these, QSI has the potential to evaluate myocyte diameter. Myocyte diameter is larger in fast-twitch muscle fibers and smaller in slow-twitch muscle fibers. In athletes, studies have shown that sprinters have more fast-twitch muscle fibers and marathoners have more slow-twitch muscle fibers. The ratio of these types of muscle fibers varies to some extent with practice but is basically determined by genetics. The assessment of this ratio is done by staining biopsies, which is invasive, and the establishment of myofiber type sorting in terms of myocyte diameter in QSI will allow non-invasive assessment of muscle function throughout the muscle. Thus, QSI is also promising from the aspect of sports medicine.

QSI Indicators and Imaging Techniques

QSI can calculate three main indices. The inverse Fourier transform of the signal attenuation curve acquired by MRI yields a diffuse displacement establishment distribution. It has three indices) Full Width at Half Maximum (FWHM [μm])) the probability for zero displacement (ZDP [a.u.])) kurtosis (kurtosis [a.u.]) [9]. At present, there are almost no reports of studies using QSI on skeletal muscles. It will be important to find out how these values correlate with skeletal muscle morphology, function, and disease.

The technical aspect of QSI is the same for pore materials, nerve regions, and skeletal muscle, and there have been many research reports on QSI. MPG, and Δ is the time between MPGs. There is a verification report that the closer to this condition, the closer to the true value [10].

Another important factor is how large the q-value (b-value) should be. If the q-value is not increased until the signal is sufficiently attenuated, high-frequency components will be ignored and truncation artifacts will occur. There are other conditions, but these conditions are very important for QSI to calculate accurate values.

Current Limitations and Future Prospects

As mentioned in the previous section, a very short and strong δ is important for QSI to calculate accurate values. However, the maximum gradient field strength of clinical MRI systems is around 40 [mT/m], and from a hardware standpoint, QSI inevitably requires a longer delta. Therefore, it must be understood that the obtained diffusion displacement probability distribution is not an accurate value. The DWI currently used in clinical practice is based on Spin Echo (SE) pulse sequences, but it is possible to achieve shorter δ by using Stimulated Echo (STE) pulse sequences. Since Callaghan's publication in 1990, the shortest delta has been achieved.

Since Callaghan's publication of QSI in 1990, many researchers have been engaged in QSI research. The scope of QSI research has broadened, but it is expected to continue to expand. In Japan, research reports on QSI have been published since around 2000, and the field of QSI has been progressing rapidly in recent years, especially in the central nervous system. Since QSI in clinical machines can be handled by DWI, it is fair to say that the groundwork for further research has already been laid. There have been few reports on skeletal muscle, and it would be no exaggeration to say that the extent to which QSI will be a valuable application for skeletal muscle is completely unknown. However, it is thought that QSI has the potential to enable the skeletal muscle evaluation described above. We hope that more research will be reported in the future and that QSI will become a useful application for skeletal muscle.

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