A 3-DOF MR Compatible Limb Positioning Manipulator to Facilitate Magic Angle Experiments in Vivo

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Introduction: Tendons and some other tissues have varying degrees of dipolar coupling as their primary relaxation mechanism. Changing the orientation of these tissues relative to the magnetic field (following well established theory) can result in very considerable extension of the effective value of T2, and much greater signals with most standard imaging sequences. Recent studies (i.e. [1]) have demonstrated the clinical and functional importance of exploiting the pronounced dipolar coupling effects in cartilage and tendons as part of the evaluation of orthopaedic and other injury. By positioning these tissues at an angle of approximately 55° (known as the "magic angle") with respect to the main field B_0, a pronounced increase of signal can be observed. These studies were made much harder by the practical difficulties of placing a tissue at a specific angle to B_0 in the confined environment of a closed bore MRI scanner. To facilitate magic angle related experiments a MR compatible device has been developed to permit controllable and accurate placement of tissues. To produce the high torques required to move heavy human limbs (such as a leg or arm), specially developed pneumatic rotary motors were fabricated. The entire system is presented and preliminary clinical trials with human volunteers demonstrate its functionality.

MR Compatible Manipulator with Air Motors: The system, which is completely MR compatible, can be seen in Fig. 1(a). The patient's limb is located on a rotational platform, which orients the tendon at the specified angle, while the motion of the X and Z axes as shown in Fig. 1(a) are calculated so that the distance from the tendon to the isocentre is minimized (and always stay within the DSV) and patient comfort is assured while rotation is taking place. A rotary air motor is used at each axis, allowing motion of the system to follow a defined trajectory. Each air motor consists of a heavily geared down turbine rotor (as displayed in Fig. 1(b)). By applying a flow of air at the rotor (at around 1 bar), high speed rotation is produced, which is then geared down (using plastic epicyclic gears) to produce elevated torques (in excess of 0.7Nm) and speeds of up to 16 revolutions per minute, enough to move a heavy limb such as a leg. To ensure positional accuracy of each axis (±1° is achieved at the rotational axis), a surface mount optical encoder with proven MR compatibility [2] was incorporated. The manipulator is located inside the scanner bore, while the system electronics, control PC and solenoid valves regulating the flow of air to each motor, were located inside the control room as indicated in Fig. 1(a). Air lines coming from the supply in the MR suite, are connected to the valves and through to the air motors in the scanner via the wave guide. The electrical pulses coming from the encoders are converted into optical signals and also led out to the control hardware. The system can be controlled by the user via an intuitive graphical interface, which allows for positioning of the system remotely from the control room.

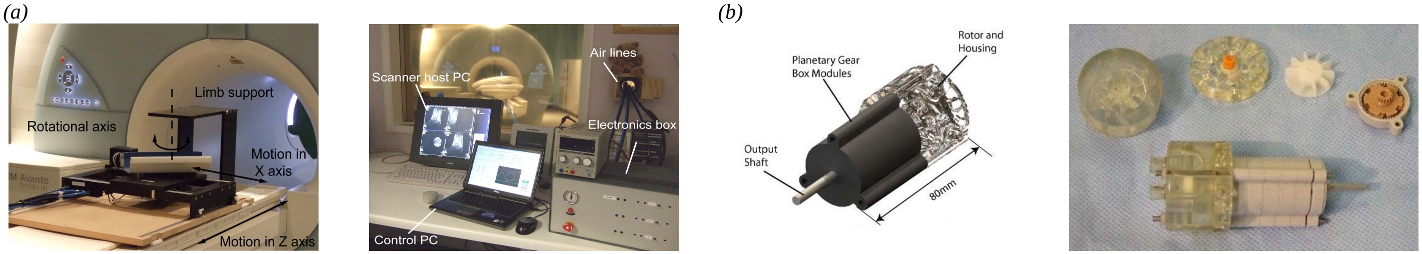

Figure 1: (a) System components, both in the scanner and control room and, (b) air motor and its parts developed for actuation of the manipulator

Preliminary Clinical Trials, Results and Conclusions: The system has been designed to be scanner independent, with preliminary experiments with human volunteers carried out on a 1.5T Siemens Avanto to prove the system's functionality. These were done by imaging the Achilles tendon, due to its size and also because positioning of the leg is the most demanding task for the system. The patients were placed in the left lateral feet first position, and their leg strapped to the rotary platform as shown in Fig. 2(a). Images were taken in 5° increments starting at 0° (aligned with B_0) up to 45°, where the increments were then reduced to 2° to observe in more detail the large increase in signal as the orientation was brought towards the magic angle. At around 60° the experiments were generally halted as most of the volunteers' knees started to collide with the scanner wall. A surface coil was used as a detector and strapped around the Achilles tendon at the ankle. The desirable image pattern is one in which the plane of the images is always transverse relative to the target tissue, and the orientation of the desired slice as well as its centre was calculated by the programme software, greatly reducing the total experiment time. The sequence used in the preliminary studies described here was a Turbo Spin Echo (TR=1800ms, TE=83ms, 5mm slice thickness, FOV=300mm, 256x256 matrix, NEX). A graph plotting the signal at the tendon vs orientation with respect to B_0 is presented in Fig. 2(b), and images at the tendon at both 0° and 55° are displayed in Fig. 2(c), showing the expected increase in signal intensity of the tendon at the magic angle. The system already shows a great flexibility and speed of operation for facilitating magic angle related experiments. Future work includes scanning not just the Achilles tendon, but a variety of tissue structures such as peripheral nerves, muscles, and tendons and cartilage in joints at the knee, elbow, wrist and hand.

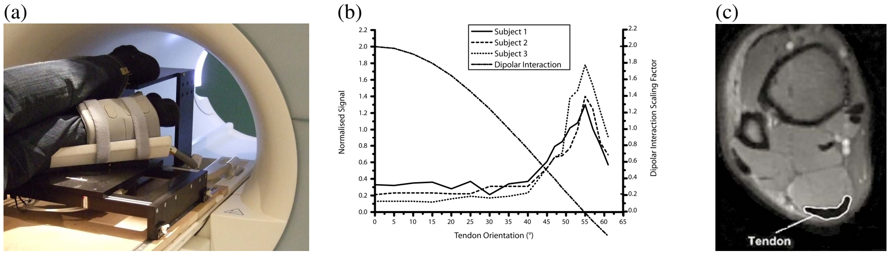

Figure 2: (a) Experimental set-up with volunteer attached to platform, (b) signal at tendon as a function of orientation and (c) image of the tendon at the magic angle, showing a clear increase in signal intensity compared to its counterpart aligned with B_0.

References:

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2. Elhawary H et al., A modular approach to MRI compatible Robotics: Interconnectable one DOF stages, IEEE Engineering and Medicine in biology magazine, 2007, accepted for publication.

Grant Support: This project is funded by DH-NEAT Grant GO19