Letters

Motion-Encoded MRIs Provide Evidence against Orbital Pulleys

Dear Drs. Piccirelli, Luechinger, Sturm, Boesiger, Landau, and Bergamin:

Your work\(^1\) with motion-encoded magnetic resonance imaging (MRI) shows the changes that occur in the horizontal extraocular muscles (EOMs) during normal horizontal eye movements. You demonstrated that the EOMs behave like other human striated muscle, except that they are unique in their small size, in their rapidity of action, and in their low nerve-to-motor unit ratio.

In adduction, the tension increases in the medial rectus muscle (MR) and decreases in the lateral rectus muscle (LR); in abduction, the tension in the LR increases and the tension in the MR decreases. These tension changes produce time-dependent changes in the shape (conformation) of the posterior two thirds of the EOMs anterior to the annulus of Zinn. The changes in shape are proportional to the amount of tension generated.

There is a potential for clinical and basic research when the dimension of time is added to MRI. You list the limitations of the method. I hope you can find a means of including the vertical muscles.

I believe that you have overlooked the most important implication of your present work. Your motion-encoded MRI confirms Sherrington’s Law of Reciprocal Innervation,\(^2\) which I believe is your major contribution. Also, it provides powerful evidence against the active pulley theory. Sherrington stated in a Stillman Lecture given at Yale University in 1904 (and I agree) that “the process of excitation and inhibition may be viewed as polar opposites. . . . the one is able to neutralize the other” and that “…desistance from action may be as truly active as is the taking of action.” Sherrington (1857–1952) won the Nobel prize in 1934 for his work in neurophysiology.

For more than 20 years, the so-called active-pulley hypothesis (APH) has dominated the thinking of researchers in the ocular motor physiology. The theory has had adverse effects on both basic and clinical research, particularly for beginning investigators. Ideas have consequences. Since you cite at least 10 publications that support the APH, you must give it credence and believe it is somehow relevant to your work.

According to the APH the orbit contains an engine (a machine with moving parts, the so-called orbital plant) composed of mobile pulleys that function independently of the brain. The recti muscles are divided into an orbital layer (OL) composed of fast-acting motor units and a global layer (GL) consisting of slow-acting motor units. Pulleys connect the epimysium of the orbital layers of the recti (OLs) to the orbital peristium by means of bands composed of elastic, smooth muscle, and collagen tissues. The OLs have an agonist-antagonist (reciprocal) relationship with the elastic bands that allows the pulley ring to move back and forth. The underside of the pulleys form collagen rings around the GLs that allow them to move in and out. It is concluded that mobile pulleys, not the annulus of Zinn, are the origins of the recti, that the axis of rotation for a given gaze direction varies with the position of the pulley, and that elastic and smooth muscle tissues can antagonize striate muscle.

My analysis of your MRI is as follows: (1) There are clear spaces between the muscles and the orbital wall, indicating the absence of connecting bands. (2) There are no inflections, notching, or tenting anywhere along the course of the MR or LR from the orbital apex to the scleral insertions. (3) There are no visible horizontal cross-condensations in the muscle parenchyma. (4) The axis of rotation remains in the same place in each time frame. (5) There is a smooth transition between the muscles and the thin tendons, which maintain the same appearance and length. There is no evidence of division of the muscle into distinct functional layers. (6) There is no evidence of coupling of the horizontal to the vertical EOMs.

In conclusion, the value of your work is that you have proven the validity of Sherrington’s Law of Reciprocal Innervation and have provided powerful evidence against the APH.

Do you agree with my analysis? Are you willing to abandon the APH and substitute your own conceptions? Finally, isn’t your term “normal deformation” an oxymoron? Isn’t “conformation” a better word to describe your normal findings?

Congratulations on your technological tour de force!

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Reference


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Author Response: Motion-Encoded MRIs Provide Evidence against Orbital Pulleys

The authors thank you for the opportunity to bring motion-encoded magnetic resonance imaging (MRI) of the orbit to wider scientific attention.

As you correctly state, the published data are in agreement with Sherrington’s Law of Reciprocal Innervation. However, computed tomography and magnetic resonance imaging (MRI) cross-sectional studies of extraocular muscles before and after ocular movement led scientific understanding to the same conclusion years ago. Motion-encoded MRI is the latest technique of image analysis. Its main strength is depiction of the change in muscle unit length within the muscle while the eye is moving.

We agree that the word choice “normal deformation” has potential for improvement. However, the word stem “conform” does not seem to precisely express our findings. In our normal population, we illustrated physiological muscle contraction and relaxation of the horizontal rectus muscles over time. We were also able to depict an abnormal innervation pattern in patients with Duane’s syndrome type I, which affected specific extraocular muscle segments only.

Motion-encoded MRI measures distances and not tensions or forces, a fact that we strictly adhered to while interpreting the image data. To mix these entities, as was the case with ultrasound imaging, would have resulted in substantial misconceptions.

The MRI method has known technical limitations in demonstrating the pulley structures directly. Its signal is optimized...