Electromagnetic Actuator for Generating Variably Oriented Shear Waves in MR Elastography

Juergen Braun,[1*] Karl Braun,[2] and Ingolf Sack[1]

Magnetic resonance elastography (MRE) is a recently developed technique for determining the mechanical properties of biological tissue. In dynamic MRE, electromagnetic units (actuators) are widely used to generate shear waves in tissue. These actuators exploit the interaction between the static magnetic field B_0 and an annular coil supplied with alternating currents. Therefore, coil movements are restricted to selected orientations to B_0. Conventional actuators transfer this movement collinearly to B_0 into the tissue. In this study, an electromagnetic actuator was introduced that overcomes this limitation. It is demonstrated that different directions of mechanical excitation can be generated and monitored by MRE. Different spatial components of the propagation of the shear waves were determined using agarose phantoms. The technique allows maximum contrast for MRE images of objects with anisotropic strain components such as muscle tissue. Magn Reson Med 50:220–222, 2003. © 2003 Wiley-Liss, Inc.

Key words: MR elastography; electromagnetic actuator; shear waves; anisotropic elasticity

Dynamic MR elastography utilizes the fact that the shear wave propagation in biological tissue is related to material stiffness (1–3). Stiffness parameters such as the shear modulus may serve to distinguish between healthy and pathologic tissues (3–5). In dynamic MRE, mechanical excitation of tissue is synchronized with phase-sensitive acquisition techniques (6). The recorded wave images show solely signal components related to tissue oscillations. In vivo, shear waves are applied by an oscillating transducer fixed to the surface of the body. The frequency range varies between 50 and 500 Hz. Electromagnetic actuators (1–3,7,8) and piezoelectric devices (9,10) have been employed as mechanical excitation units. Although the latter can be positioned in arbitrary orientations with respect to B_0, the construction is quite elaborate and time-consuming. Electromagnetic actuators are easier to construct, cost less, and can be customized easily to account for special in vivo applications such as muscle, breast, or brain MRE (11,12). Applying alternating currents to an annular coil generates motion. A maximal torque acts on the coil if the normal vector of its plane is perpendicular to B_0. The resultant periodic tilt is transformed for mechanical actuation using a pivoted rod. In this commonly used design, the orientation of the actuator coil restricts the directions available for mechanical excitation. For isotropic tissue, the direction of shear wave displacement has no influence on the determination of the shear modulus. However, in anisotropic tissue such as skeletal muscles (7,8) or pathologic tissue (3), the propagation speed of the shear waves should be determined in different spatial directions. In these cases, actuators with a variable direction of excitation are required to gain full information about tissue characteristics.

In this study, an electromagnetic actuator is introduced that allows harmonic excitations with directions between 0° and 90° to the B_0 field to be generated. To demonstrate the feasibility of the new actuator, experiments on agarose phantoms are presented and compared with the performance of a conventional electromagnetic actuator. Displacement components parallel and orthogonal to the B_0 field are compared for the conventional and the new actuator.

MATERIALS AND METHODS

Construction of the Actuator Unit

Figure 1a shows a schematic of a conventional actuator design. For clarity, a coordinate system is introduced where the *z*-axis is collinear to B_0. The normal vector to the plane of the actuator coil [1] must be oriented perpendicularly to B_0. A carbon fiber tube [2] connects the coil with the excitation plate [5], which is positioned on the surface of the object under investigation. Applying an alternating current results in periodic oscillation of the coil around the *x*-axis. This motion is transferred by an axis [3] mounted on a base plate [4] and mechanically linked with the tube [2]. This construction allows shear wave excitation only parallel to B_0. The new actuator design (Fig. 1b) results from adding a pivoted redirection plate [6] connected with the tube carrying the actuator coil. The axis between the pivot point [8] and the connecting point of the tube [7] lies perpendicular to the tube's plane of motion. The redirection of the initial motion is determined by the angle between the connecting point of the tube [7], the pivot point [8], and the inserting point of the excitation plate [9]. An angle of 90° (Fig. 1b) results in a shear wave excitation perpendicular to B_0. Other angles can be chosen by varying the position of the excitation plate in the different inserting points. Figure 1c shows a cross section of the actuator and details of the connection between tube [2] and redirection plate [6]. A ball-shaped head made of brass was securely fitted into the plate. The head of the ball [11] was pressed into a Teflon cylinder [10] fixed with a bushing [12] to the tube to form a gimbal joint.

Methods

Data were acquired on a 1.5 T scanner (Siemens Magnetom Vision, Erlangen, Germany). A modified echo planar im-

[1]Department of Medical Informatics, Benjamin Franklin Medical Center, Free University of Berlin, Berlin, Germany.
[2]Hauptstrasse 10, 79215 Elzach, Germany.
Grant sponsor: the Ernst Schering Research Foundation (to I.S.).
*Correspondence to: Dr. Jürgen Braun, Universitätsklinikum Benjamin Franklin, WE 10, Hindenburgdamm 30, 12200 Berlin, Germany.
E-mail: braun@medizin.fu-berlin.de
Received 9 August 2002; revised 14 February 2003; accepted 14 February 2003.
DOI 10.1002/mrm.10479
Published online in Wiley InterScience (www.interscience.wiley.com).