modes to help build muscle strength and to monitor movements for later analysis. The support to the muscle is defined by the position of the actuator **12** applying force to the moving parts of the brace. Namely, as the actuator **12** rotates, and with it the moving (rigid) parts of the brace, the position of the actuator **12** defines the relative position of the joint and thereby supporting the corresponding muscle.

STRUCTURE AND BODY ATTACHMENT

[**0026**] Each device provides assistance and/or resistance to the muscles that extend and flex one joint. The device does not directly connect to the muscle, but is attached in such a way that it can exert external forces to the limbs. The device is built from an underlying structural frame, padding, and straps (not shown) that can be tightened to the desired pressure. The frame structure with hinged lower and upper portions (**14** and **16**) as shown is preferably made of light-weight aluminum or carbon fiber.

[**0027**] In this embodiment, the frame is attached to the upper and lower leg with straps held by Velcro or clip-type connectors (not shown). A soft padding material cushions the leg. The brace may come in several standard sizes, or a custom brace can be constructed by making a mold of the leg and building a brace to precisely fit a replica of the leg constructed from the mold.

[**0028**] The attachment of the device to the body is most easily understood with respect to a specific joint, the knee in this case. The structural frame of the device includes a rigid portion above the knee connected to hinges **18** at the medial and lateral sides. The rigid structure goes around the knee, typically around the posterior side, to connect both hinges together. On the upper portion of the brace **16**, the rigid portion extends up to the mid-thigh, and on the lower portion **14**, it continues down to the mid-calf. In the thigh and calf regions, the frame extends around from medial to lateral sides around approximately half the circumference of the leg. The remaining portion of the circumference is spanned by straps that can be tightened with clips, laces or Velcro closures. Understandably, this allows easier attachment and removal of the device. The rigid portion can be either on the anterior or posterior side, but because this device must exert more pressure to extend the knee than to flex the knee, the preferred structure is to place more of the rigid structure on the posterior side with the straps on the anterior side. The number and width of straps can vary, but the straps must be sufficient to hold the device in place with the axis of rotation of the hinge in approximately the same axis as that of rotation of the knee. The hinge itself may be more complex than a single pivot point to match the rotation of the knee.

[**0029**] Cushioning material may be added to improve comfort. A manufacturer may choose to produce several standard sizes, each with enough adjustments to be comfortable for a range of patients, or the manufacturer may use a mold or tracing of the leg to produce individually customized devices.

[**0030**] As will be later explained in more detail, a microcontroller-based control system drives control information to the actuator, receives user input from a control panel function, and receives sensor information including joint position and external applied forces. For example, pressure information is obtained from the foot-pressure sensor **19**. Based on the sensor input and desired operation mode, the control system applies forces to resist the muscle, assist the muscle, or to allow the muscle to move the joint freely.

[**0031**] The actuator **12** is coupled to the brace to provide the force needed to assist or resist the leg muscle(s). Although it is intended to be relatively small in size, the actuator is preferably located on the lateral side to avoid interference with the other leg. The actuator is coupled to both the upper and lower portions of the structural frame to provide assistance and resistance with leg extension and flexion.

[**0032**] As the examples below will demonstrate, the actuator **12** is structured to function as an electrostatic motor, linear or rotational (examples and implementations of electrostatic actuators can also be found in U.S. Pat. Nos. 6,525,446, 5,708,319, 5,541,465, 5,448,124, 5,239,222, which are incorporated herein by reference for this purpose). The idea being that the actuator is configured with the stator and rotor each having a plurality of electrodes electrically driven in opposite direction to cause an electrostatic field and, in turn, movement. The strength of the electrostatic field determines the amount of torque produced by the actuator. The electrostatic motor can be fabricated as a 2-dimension structure that can be easily stacked for producing higher power. This configuration is light weight relative to a 3-dimension structure of electromagnetic motors and can be constructed from light-weight polymers instead of heavy iron-based magnetic materials.

[**0033**] One example of an actuator is known as dual excitation multiphase electrostatic drive (DEMED) consisting of two films, slider and stator, both configured with three-phase parallel electrodes covered with insulating material. The velocity of the movement of the slider-relative to the stator is controlled by the electrostatic interaction between the potential waves induced on the electrodes when a-c signals are applied to them, respectively.

[**0034**] **FIG. 2***a* illustrates a basic linear electrostatic actuator with a stator and slider driven by a 3-phase a-c signal (alternating current signal). The three signals are preferably offset by $2\pi/3$ and thus constitute the 3-phase a-c signals. The electrode strips (conductors **30**-**41**) are arranged sequentially in three groups, and the arranging order of the electrodes in the stator **24** is reversed with respect to the arranging order of the electrodes in the slider **22**. The electrodes strips in both the stator and slider are implanted on an insulating dielectric material that allows the slider to glide over the stator without shorting the strips. By applying the 3-phase a-c signals to the electrodes (**30**-**41**), traveling potential waves are induced on the stator and the slider. The connecting order of the three phases in the slider are reversed from that in the stator. So the induced potential waves in the slider **22** and stator **24** propagate in opposite directions, but their velocity is similar. The waves having offset phases generate a Coulomb force between the electrode strips of the stator and slider from static electricity; and the Coulomb force moves the slider relative to the stator (in this configuration) along the arranged direction of the electrode strips. Namely, the slider is driven by electrostatic interaction between the two waves and its speed, v, is the differential between the speeds of the waves, i.e., twice the traveling wave velocity.

[**0035**] **FIG. 2***b* shows the two parts of a rotary type electrostatic actuator: the stator **201** and the rotor **203** which