The Elastic Function of the Lumbar Fascia in Human Gait

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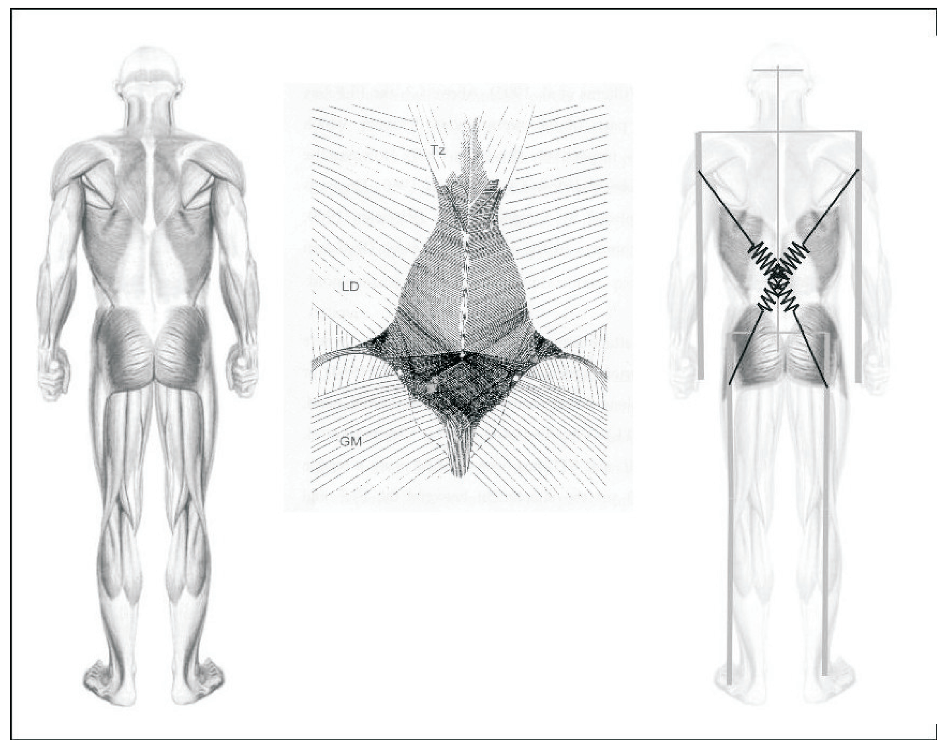
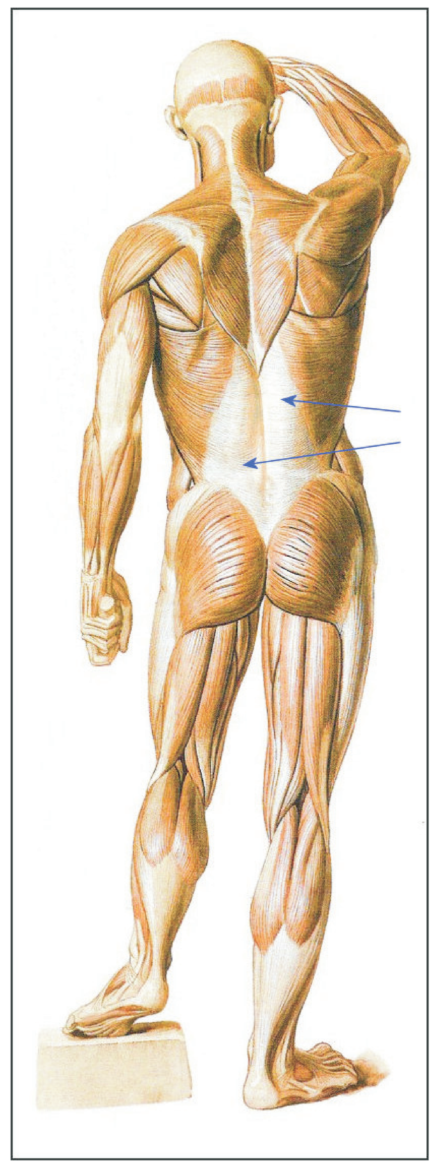
Motivation

The Lumbodorsal Fascia is a large structure, located in a central position in the human body. Acting as a sheet-like tendon it directly connects two of the strongest muscles of the body (the m.gluteus maximus and the m.latissimus dorsi).
To our knowledge there have not been any detailed research about the role of the LDF in human locomotion yet.
We are introducing the hypothesis that the LDF acts as an elastic spring that connects the pendulums of the legs and arms. This way a structure is established which is able to oscillate as a whole (Zorn2007).



The criss-crossing fiber structure
Image in the center from Vleeming(1995)

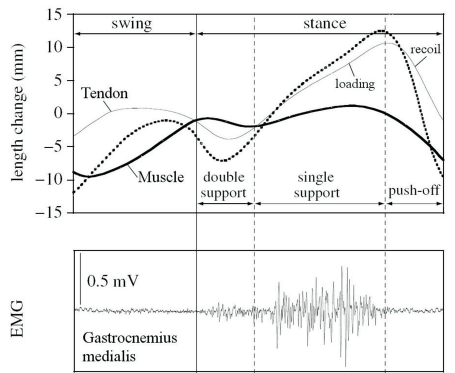


The Lumbodorsal Fascia
Image from Sobotta(1993)

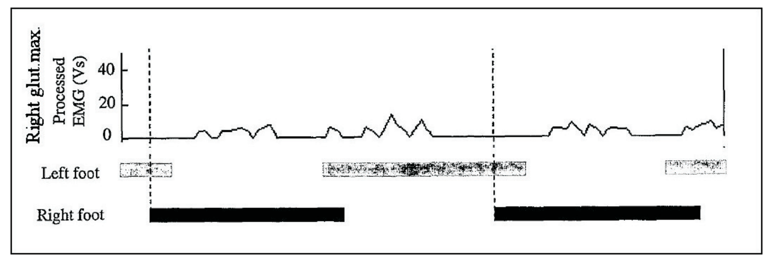
Background

1) The superficial lamina of the posterior layer of the LDF is the tendon/aponeurosis of the latissimus dorsi muscle. To some part it is as well the cranial aponeurosis of the gluteus maximus muscle thus "providing a pathway for uninterrupted mechanical transmission between pelvis and trunk" (Vleeming 1995). In accordance to this pathway its fibers show a criss-crossing structure, although anatomy charts differ displaying the particular fiber structure. There are no data available for the elastic properties of the LDF in vivo, but it seems likely that the LDF has an elastic modulus comparable to those in human ligaments and tendons (Barker2005, Alexander 2002). From this, it can be concluded that the LDF is able to store a significant amount of energy when being stretched.

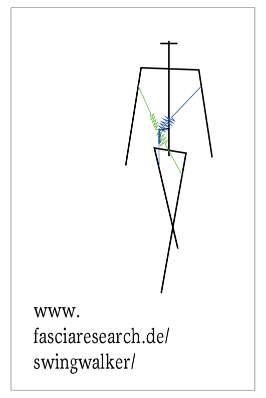
2) There is a significant body of evidence that in a walking person the gluteus maximus muscle shows a timed EMG activity as if intended to restrain the forward swinging leg. Data on the EMG activity of the latissimus dorsi muscle during gait are rare. The available data show an equal "braking" behaviour for the forward swinging arm (e.g. Ivanenko 2006). Fukunaga (2002) proved that a similar timed activity of the gastrocnemius muscle puts the achilles tendon into a pre-stretch in walking. While the muscle is working isometrically the tendon is stretched by the inertia of the body movement like the spring in a spring pendulum. The same mechanism was suggested for the LDF (Zorn 2007).

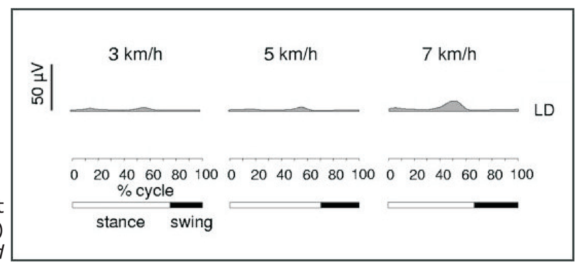


The activity of m.gastrocnemius and achilles tendon length during gait (Fukunaga 2001)
Notice that the tendon is doing the work during push-off



The activity of m.glut.max. during gait (Liebermann 2006)
Notice the muscle activity while the leg is swinging forward

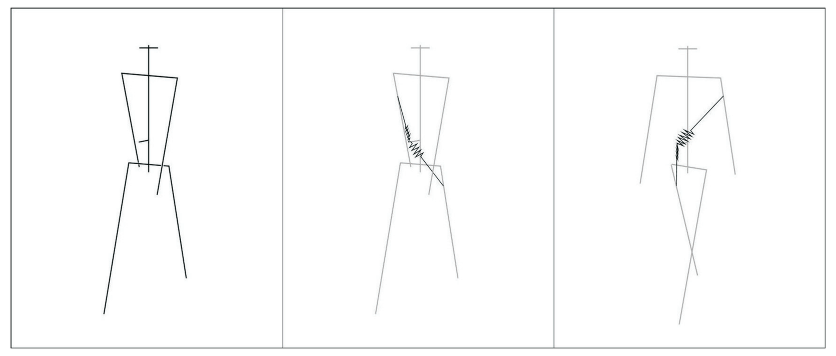




The activity of m.lat.dorsi of the collateral leg during gait (Ivanenko 2006)
Notice the muscle activity while the arm is swinging forward

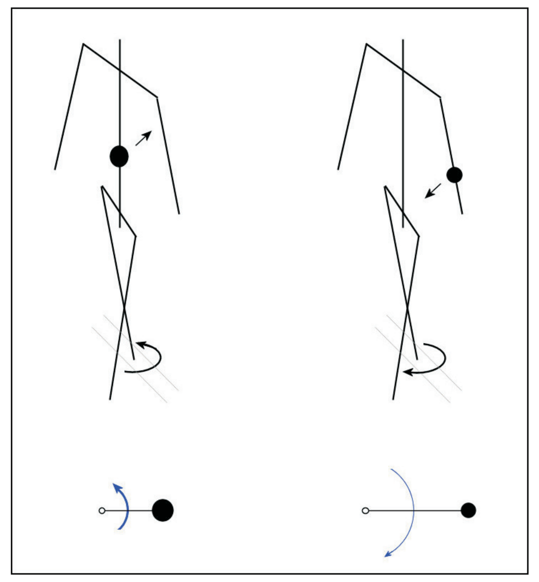
Hypothesis

1) Because of the analogous patterns of the EMG activity of the mm. gluteus maximus and latissimus dorsi compared to the m. gastrocnemius it can be hypothesized that these two muscles provide an isometrical pre-stretch of the LDF. This way the arms can swing in synchronicity with the legs without much (phasic, concentric) muscular effort.



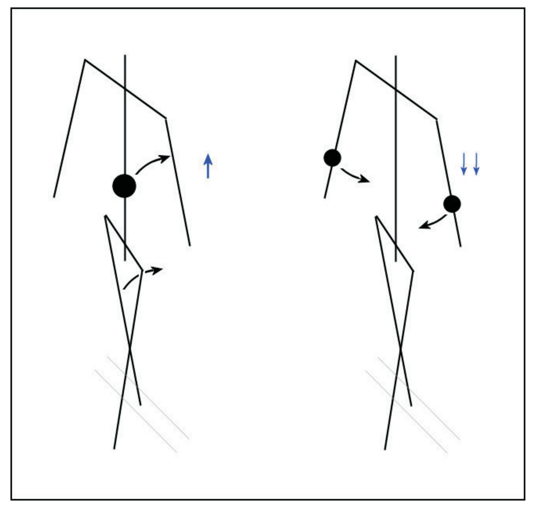
2) We developed a basic mechanical model of two torsion pendulums (shoulders/LDF-spring and pelvis/LDF-spring) rotating in the transversal plane, two inverted pendulums (legs) and two suspended pendulums (arms). The mm. latissimus dorsi and gluteus maximus are represented by inelastic cords just maintaining constant length. The springs have the double function of establishing the reset-momentum for the torsion pendulums and connecting the shoulder/arms and pelvis/leg structures. Being a set of harmonic oscillators (i.e. having no friction) this kinetic model can swing forever whithout consuming further energy.

3) The movement of the center of mass (CoM) of the body over a leg that is located sideways produces a significant moment of torque acting on the supporting foot. The counter-swing of the contralateral arm cancels out to some part this torque (Elftman1939). We hypothesize that for given pelvis and leg swing amplitudes there is an optimum combination of shoulder and arm swing amplitudes which cancels out an optimum amount of torque.



The torque in the foot due to the movement of the mass of the trunk and the torque due to the movement of the contralateral arm act in opposite directions. Below top view.

4) The movement of the CoM of the body over the standing leg shows a vertical up and down. For energetic efficiency it is of crucial importance to minimize the loss of the potential energy during the downward movement or transform it into other kinds of energy for re-use. One well known way of doing this is the inverted pendulum mechanism of the legs (Cavagna1977). Another way is provided by the arms: Their vertical component of swinging is in counter-phase with the trunk thus reducing the up and down of the CoM of the whole body (Hinrichs1990). We hypothesize that the same parameters fulfilling the optimum cancel-of-torque condition provide as well a significant reduction of the vertical oscillations of the trunk mass.



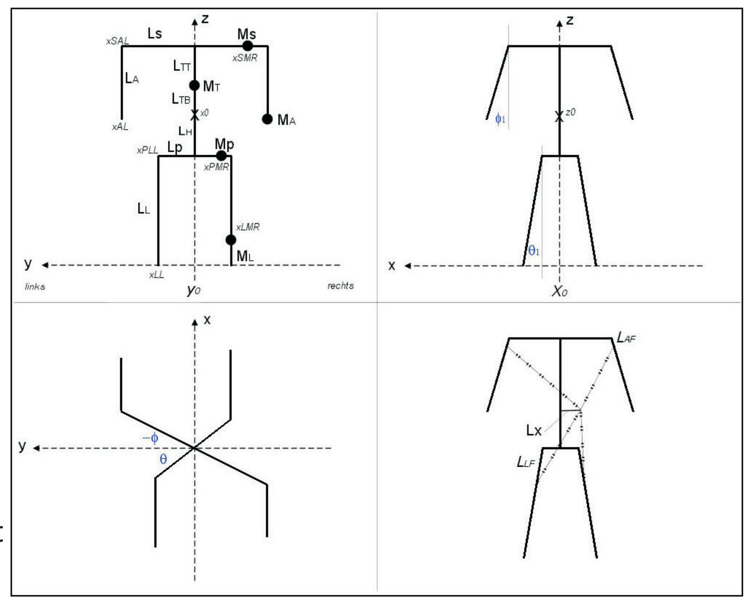
While the leg lifts the trunk mass upward the arm masses move downward and thus reduce the total lift work

Methods

We describe the kinetics of this model body using accurate mathematical treatment of applied mechanics. Anthropo-metric data (lengths of the pendulums, masses and centers of segment masses) are taken from Winter (1990). The spatial dimensions of the LDF were taken from Barker (2005) and the Visible Human Project. Amplitudes of pelvic rotation and stride length are according LaFiandra (2003). The model body set of interconnected oscillators in the gravity field was treated using the Lagrange formalism.

The obtained set of differential equations $\frac{d}{dt}\frac{\partial L}{\partial \dot{q}_i} - \frac{\partial L}{\partial q_i} = 0$

was solved numerically with MapleTM software. Amplitudes of shoulder rotation and arm swing were chosen in view of minimum moment of torque in the foot (parameter fitting).



Results

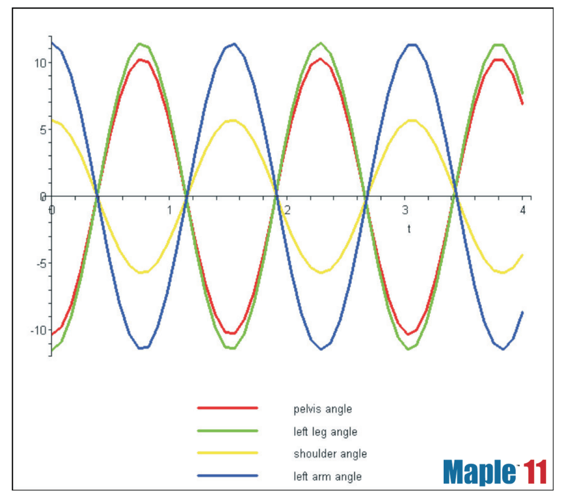
For the chosen set of initial conditions and constraints ...

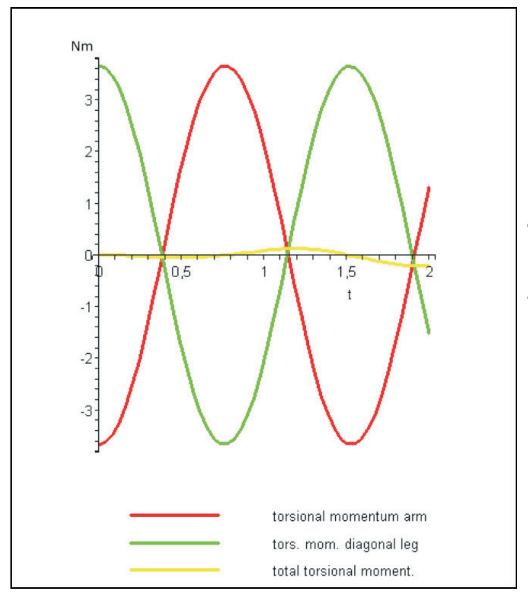
$\theta1_{max} = 12°$ amplitude of the leg swing

$\theta_{max} = 0.9 * \theta1_{max} = 10.8°$ amplitude of the pelvis swing

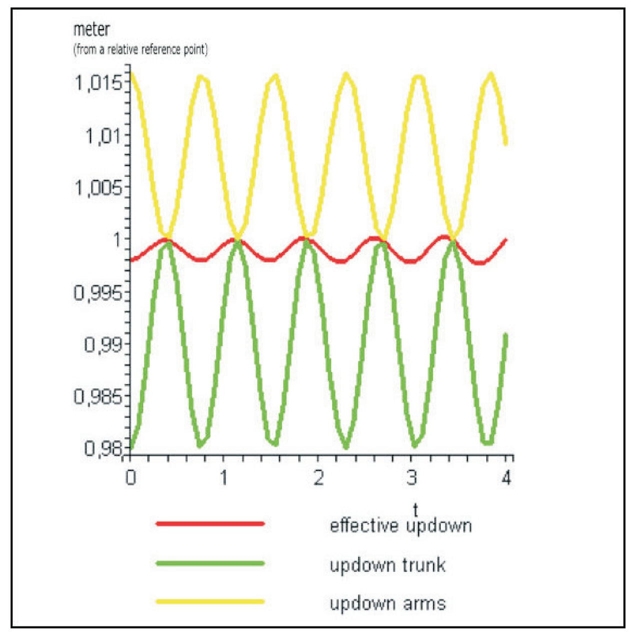
$\varphi1_{max} = 12°$ amplitude of the arm swing

$\varphi_{max} = 0.5 * \varphi1_{max} = 6°$ amplitude of the shoulder swing





... the moment of torque in the foot is almost completely cancelled out for the first swinging cycles.
(Coupled harmonic oscillators - no dissipation by friction and no muscle excitation - are not able to maintain phase synchronicity.)



... and the up and down movement of the trunk mass is almost completely cancelled out by the vertical component of the arm movement.

Conclusion

If the mm. gluteus maximus and latissimus dorsi work isometrically the Lumbodorsal Fascia acts as an elastic structure that

- establishes a torsion pendulum together with the shoulder and another one with the pelvic girdle,
- connects the oscillating pendulums of the arm with the contralateral leg.

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