ROLE OF REFLEX DYNAMICS IN SPINAL STABILITY

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INTRODUCTION

Reflexes play an important role in the control of spinal stability. Three sub-systems contribute to stability including: 1) passive spinal ligaments, discs and bone, 2) intrinsic viscoelastic stiffness of muscles during steady-state activation, and 3) neural feedback including reflex and voluntary responses. Existing biomechanical models assume spinal stability is maintained by intrinsic stiffness of active muscle. However, it is unclear whether intrinsic stiffness alone can sufficiently compensate for the gradient in gravitational moment at each vertebra. Reflex response also contributes to spinal stability; they provide restorative forces similar to intrinsic stiffness but are time-delayed by response latency. The reflex response in the torso and paraspinal muscles may contribute significantly to the stabilizing control spine. Therefore, the goal of this study was to quantify the role of reflexes in spinal stability during voluntary isometric extension exertions.

METHODS

Eleven healthy males with no history of low back pain participated after signing informed consent. Subjects generated isometric trunk extension exertions (20, 35, 50% MVE) while pseudo-random binary position disturbances, ±2 mm amplitude, were applied to the T10 level of the torso. Measured force was represented as the sum of intrinsic stiffness and reflex responses (Figure 1). The intrinsic pathway \( H_{\text{INT}} \) described the viscoelastic response to disturbances. \( H_{\text{INT}} \) duration was fixed at less than 40 msec, i.e. less than measured reflex delay, to ensure that reflex mechanisms would not influence the estimated, \( H_{\text{INT}} \). Force not accounted for by the intrinsic dynamics was attributed to reflex, i.e. force at t>40 msec. The reflex pathway was modeled as a delayed Hammerstein series with dynamic linear element, \( H_{\text{REF}} \). \( H_{\text{INT}} \) and \( H_{\text{REF}} \) were iteratively computed until successive cycles failed to improve model accuracy.

Intrinsic compliance was parametrically modeled as a 2nd order behavior (Figure 1, \( H_{\text{INT}} \) box). \( P_{\text{INT}} \) was operationally defined as the proportional intrinsic response coefficient

\[
P_{\text{INT}} = k_{\text{INT}} - M g h^{-1}
\]

in the model and included intrinsic stiffness, \( k_{\text{INT}} \), as well as gravitational contributions to measured force. The reflex impulse response function, \( H_{\text{REF}} \), was parameterized using a model of a standard 2nd order system in series with a reflex delay (Figure 1).

\[
H_{\text{REF}}(s) = \frac{G_{\text{REF}}}{s^2 + 2\zeta\omega_n s + \omega_n^2} e^{-\zeta s} \\
\text{(eqn 2)}
\]

Reflex conduction delay was determined from visual inspection of \( H_{\text{REF}} \). Parameters were computed by least-mean-square fit to measured data, Levenberg-Marquardt algorithm. ANOVA were performed to determine the effect of independent variables of trunk extension exertion on the proportional intrinsic response, \( P_{\text{INT}} \), and reflex parameters.
RESULTS AND DISCUSSION

Nonlinear system identification procedures predicted the total force response to the pseudorandom position perturbations with accuracy of 80.9 ±3.6%. Typical intrinsic force response exhibited large inertial force at the onset of the movement perturbation, i.e. acceleration phase (Figure 2). This was followed by a steady-state force proportional to the position disturbance. Mean value of proportional intrinsic response, $P_{\text{INT}}$, was not significantly different than zero (Table 1). Gravitational contribution to $P_{\text{INT}}$ was -1695 ±249 N/m. Therefore, from equation 1 the mean intrinsic stiffness was $k_{\text{INT}} = 1281 ±240$ N/m during the 20% MVE exertions. This increased significantly up $k_{\text{INT}} = 2116 ±710$ N/m during 50% MVE exertions.

Figure 2. Typical sample of position disturbance, intrinsic and reflex force components.

Intrinsic stiffness alone was insufficient to stabilize gravitational effects of torso mass. When the spine and torso are disturbed from the equilibrium then intrinsic stiffness, $k_{\text{INT}}$, provided restorative forces that tend to return the posture toward the equilibrium state, i.e. positive contribution to $P_{\text{INT}}$. Conversely, gravitational mass contributes destabilizing forces that tend to drive the posture away from the equilibrium state following a small disturbance, i.e. negative contribution to $P_{\text{INT}}$. The negative contribution of gravitational mass was often greater than the positive contribution of the intrinsic muscle and passive tissue stiffness.

Mean value of reflex gain, $G_{\text{REF}}$, was 221 ±84 N-s/m and increased (p < .05) with exertion. Mean reflex natural frequency and damping ratio were 9.13 ±2.1 Hz and 0.58 ±0.12 N-s$^2$/m respectively. These were not significantly influenced by exertion effort.

The contribution of reflexes to the total stiffness behavior was estimated from equation 2. Recall that $H_{\text{REF}}$ describes the transfer function from disturbance velocity to reflex force. Hence, the proportional response to describe reflex stiffness is $k_{\text{REFLEX}} = \frac{G_{\text{REF}}}{2\zeta\omega_0} e^{-\zeta\omega_0 t}$. Standard first-order Pade approximation was used to account for the reflex delay. Mean reflex stiffness was 1398 ±963 N/m (Table 1). Therefore, 42% of the total trunk stiffness can be attributed to the reflex response. There was no statistical difference in the reflex contribution to trunk stiffness between exertion levels.

SUMMARY / CONCLUSIONS

This study provided insight into the significant role that reflexes play in trunk dynamics and spinal stability. Without reflex response the system was often unstable. Recognizing that reflexes may account for up to 42% of the stabilizing dynamics of the torso future models should include reflexes. Results also indicate that individuals with disturbed reflex response may be more susceptible to spinal instability injuries.

Table 1. Mean (standard deviation) values of intrinsic and reflex parameters. Superscript represent significant differences (p<0.05) between exertion conditions.

<table>
<thead>
<tr>
<th></th>
<th>Force [N]</th>
<th>$P_{\text{INT}}$ [N/m]</th>
<th>$k_{\text{INT}}$ [N/m]</th>
<th>$G_{\text{R}}$ [N/s]</th>
<th>$\zeta$ [N s/m]</th>
<th>$\omega_0$ [Hz]</th>
<th>$k_{\text{Reflex}}$ [N/m]</th>
</tr>
</thead>
<tbody>
<tr>
<td>20% MVE</td>
<td>96 (20)$^A$</td>
<td>-415 (354)$^A$</td>
<td>1280 (240)$^A$</td>
<td>197 (96)$^A$</td>
<td>0.66 (0.14)$^A$</td>
<td>8.69 (2.74)$^A$</td>
<td>1205 (990)$^A$</td>
</tr>
<tr>
<td>35% MVE</td>
<td>155 (38)$^B$</td>
<td>43 (637)$^B$</td>
<td>1738 (600)$^B$</td>
<td>221 (79)$^A$</td>
<td>0.55 (0.08)$B^B$</td>
<td>9.54 (2.23)$^A$</td>
<td>1368 (926)$^A$</td>
</tr>
<tr>
<td>50% MVE</td>
<td>208 (65)$^C$</td>
<td>421 (796)$^B$</td>
<td>2116 (710)$^B$</td>
<td>248 (77)$^B$</td>
<td>0.53 (0.12)$B^B$</td>
<td>9.16 (1.43)$^A$</td>
<td>1619 (1024)$^A$</td>
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