THE DYNAMIC RESPONSE OF THE HUMAN SPINE TO LOW AMPLITUDE HIGH VELOCITY POSTEROANTERIOR THRUSTS

NATHAN M, LEHNEMAN JB, KELLER TS.

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INTRODUCTION

A biomechanical analysis of the spine is important for understanding the response to and the efficacy of chiropractic manipulations. While many previous studies have focussed on the static (DC) and quasi-static (<5 Hz) biomechanical response of the human spine,[1-3] only limited information (primarily animal studies) exists concerning the dynamic biomechanical response of the spine.[4,5] The objective of this study was to quantify the frequency-dependent or dynamic biomechanical characteristics (impedance, mobility, stiffness) of the normal human thoraco-lumbar spine in response to low amplitude, high velocity posterior-anterior (PA) thrusts. Based upon previous work,[5] we hypothesized that the biomechanical characteristics of the spine would vary as a non-linear function of the loading frequency.

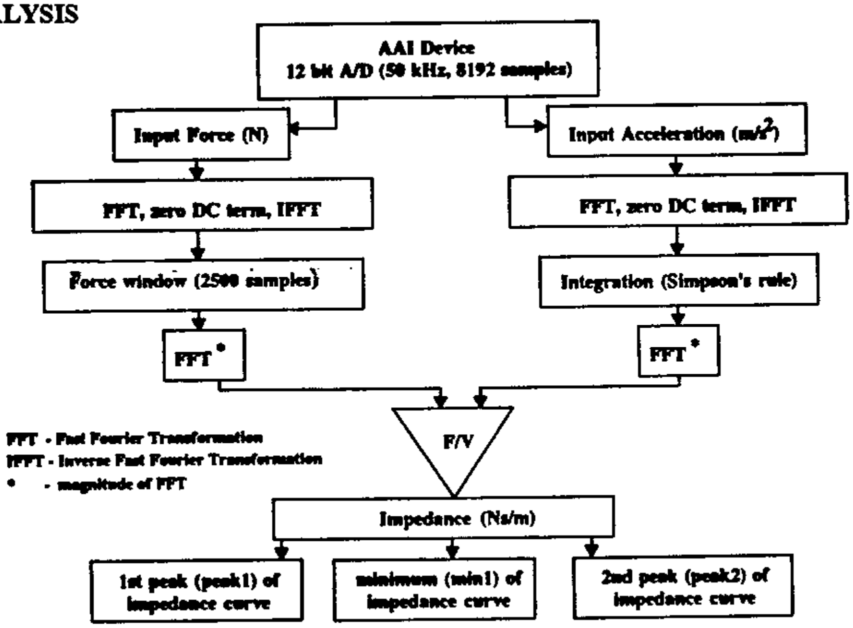
1. IMPULSE DELIVERY PROTOCOL

An Activator Adjusting Instrument (AAI) equipped with an impedance head (load cell + accelerometer) was used to deliver PA thrusts to the spinous processes (T7, T9, T11-S2) of 11 subjects. The impulse delivery protocol was approved by the University of Vermont Institutional Review Board, and all subjects signed an informed consent. Five males and six females with no previous history of low back pain or spine related surgery were subsequently examined. With the subjects prone, the location of each spinous process was determined by palpation, and identified with adhesive markers. For each subject, 5 repeated impulses were delivered at 10 spinal levels. The subject was requested to inhale and the impulse was delivered at the end of the expiration of breath. Subject demographics are summarized below.

SUBJECT DEMOGRAPHICS

	MALES (N=5)	FEMALES (N=6)
Age (years)	26.8±7.8	24.5±3.7
Weight (kg)	76.6±11	58±8.2
Height (cm)	179.7±10.5	164.2±5.9

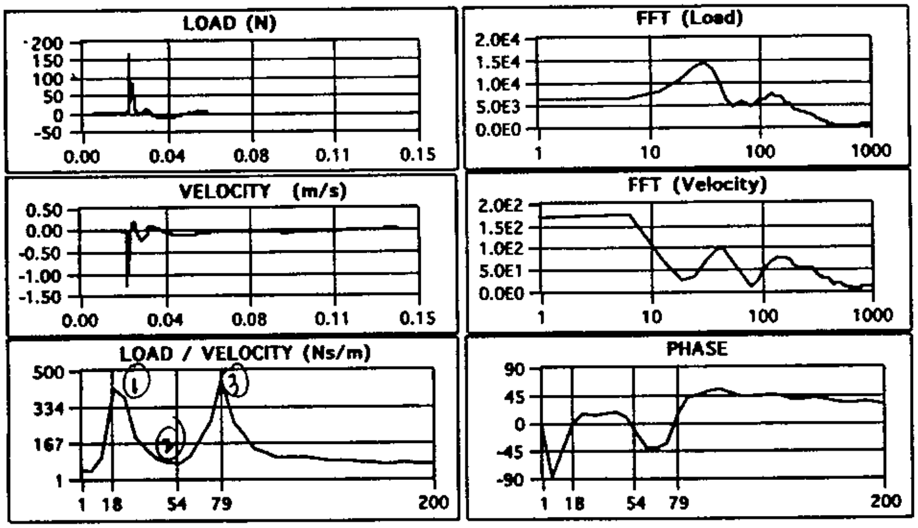
2. IMPULSE DATA ANALYSIS



Force (*F*) and acceleration (*a*) signals were sampled at 50 kHz using a 12 bit A/D converter for 160 msec. The effects of any DC offset in the *F* and *a* signals were removed by applying the Fast Fourier Transformation (FFT) to each signal, setting the DC term to zero and applying the Inverse FFT. The acceleration-time signal was integrated using Simpson's rule to derive the impulse velocity. A force window (50 msec wide) was applied to the zeroed force-time signal. PA impedance was calculated at each discrete frequency, as the ratio of FFT(force)/FFT(velocity)*, along with the phase difference between the force and velocity.

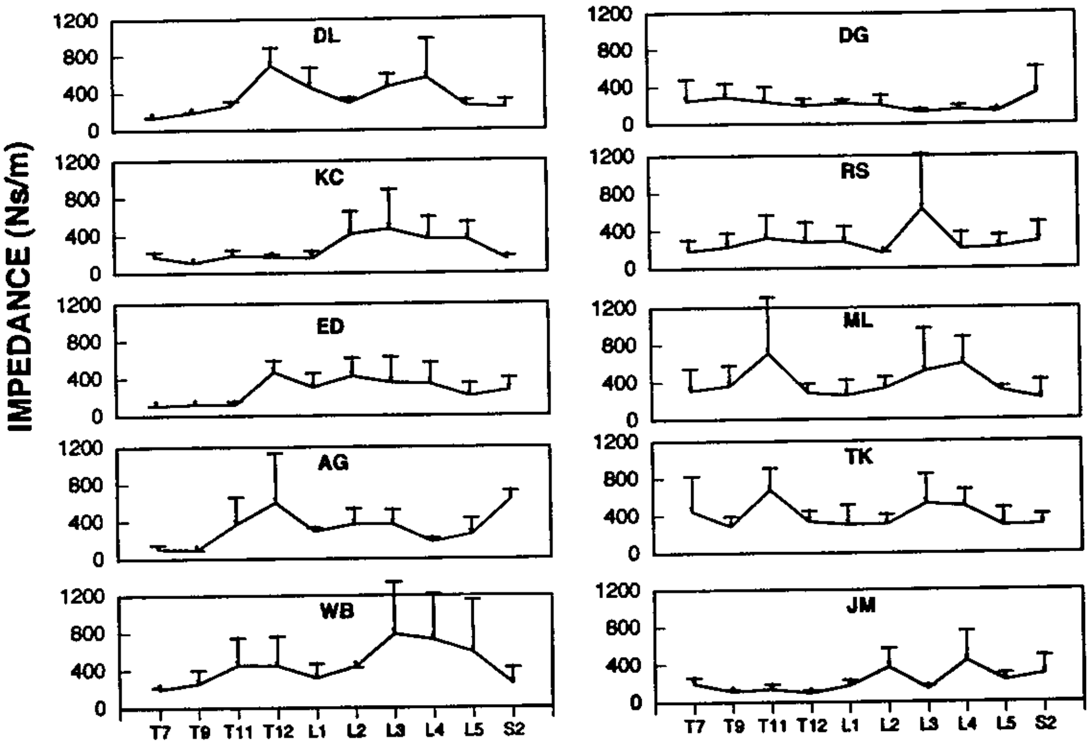
*The impedance results presented in this poster differ from those presented in the abstract due to the fact that the velocity-time traces were not windowed as per our original analysis. The decision not to window the response data was based upon the finding that the impedance calculations are extremely sensitive to the windowing procedure used.

3. PARAMETERS MEASURED FROM THE IMPEDANCE (FORCE/VELOCITY) CURVE



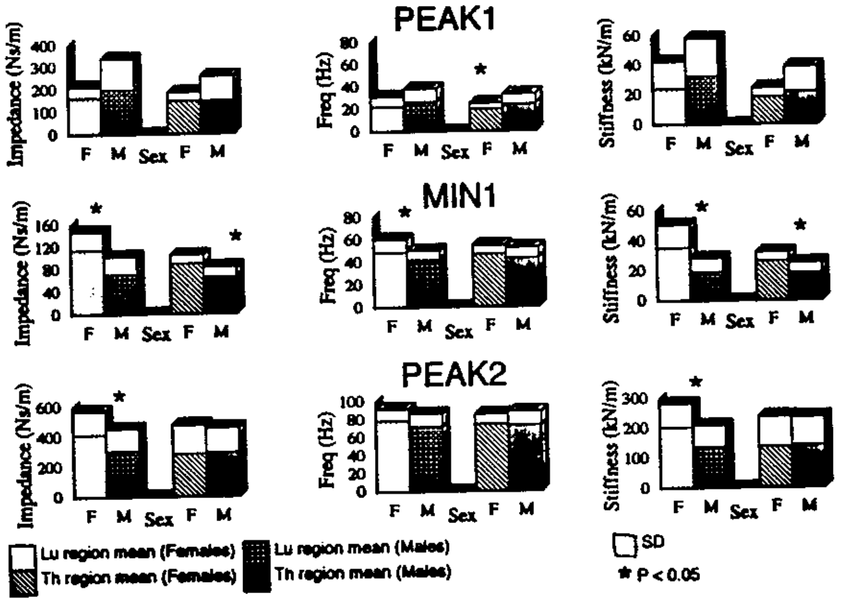
For each spinal level impacted, single, ensemble averaged impedance and phase curves were derived from the 5 traces. Three parameters were identified for each impedance curve: (1) 1st peak (peak1), (2) 1st minimum (min1 or max mobility), and (3) 2nd peak (peak2 or max impedance); together with the frequency (*f*) at which each occurred. These frequency peaks/valley were readily identified and were associated with a rapid change in phase (±45°). The PA dynamic stiffness was calculated as the product of the impedance and the circular frequency ($2\pi f$).

4. PA IMPEDANCE (PEAK2) CHARACTERISTICS OF THE THORACO-LUMBAR SPINE



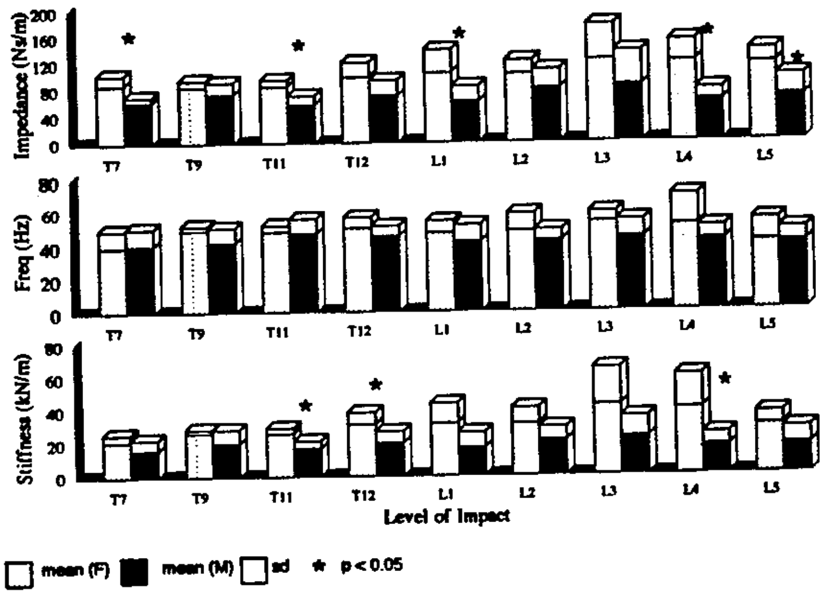
This figure graphically illustrates the variation in the maximum (peak2) impedance (mean + SD) for five of the female subjects (one female not shown) and five male subjects. The maximum PA impedance of the thoraco-lumbar spine ranged from 200 - 800 Ns/m for levels T7 - S2 and occurred between 70 - 100 Hz. Most subjects (males and females) exhibited a bimodal impedance distribution: higher PA impedance at spinal levels T11/T12 and L3/L4 when compared to other levels. For 5 repeated impulses, variances (100 * SD/mean) in the impedance data tended to be about 25 - 50 %.

5. COMPARISON OF IMPEDANCE CHARACTERISTICS: MALE vs FEMALE SUBJECTS



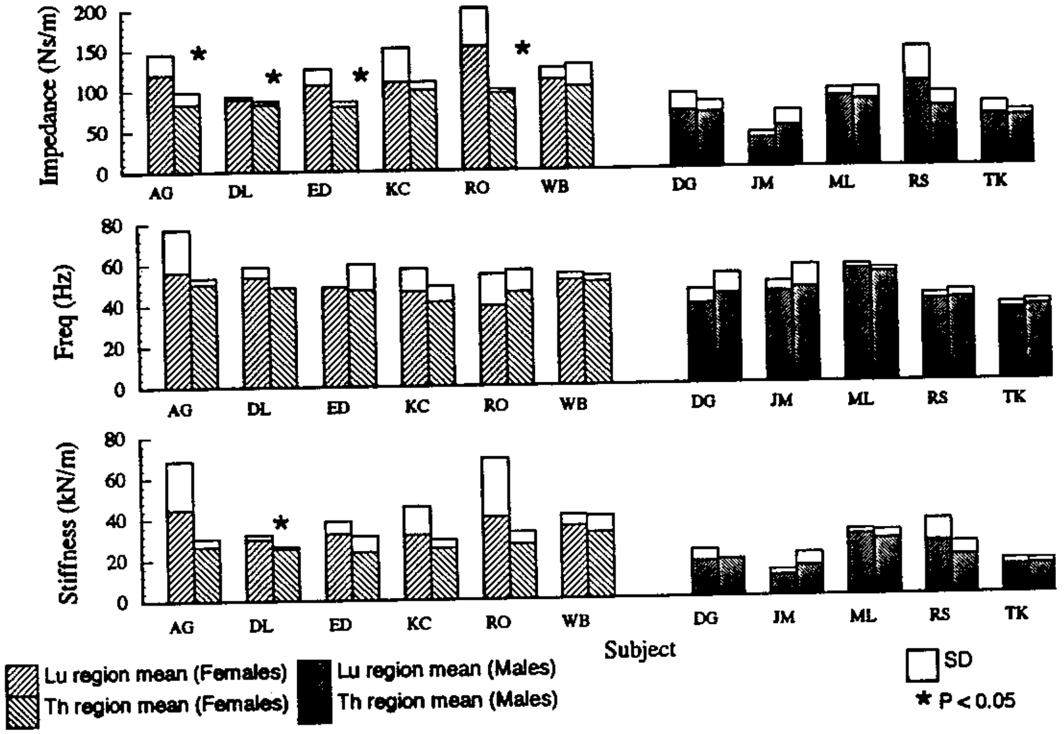
These graphs illustrate the differences in spinal impedance (left), and frequency (middle) and the stiffness (right) for the combined thoracic levels and combined lumbar levels of the male and female subjects corresponding to peak1 (top), min1 (middle) and peak2 (bottom). Note that in both the thoracic and the lumbar regions the male subjects tend to be stiffer (higher impedance) than the female subjects at the first peak (lowest frequency, 20-30 Hz) but are less stiff at higher frequencies (min1 40-50 Hz and peak2 70-80 Hz). Statistically significant differences (P<0.5 indicated by *) in stiffness and mobility between males and females were noted, particularly for frequencies corresponding to the maximum mobility (min1) and minimum mobility (peak2).

6.COMPARISON OF MIN1 IMPEDANCE AT EACH LEVEL (MALES vs FEMALES)



When compared to the male subjects, the females exhibited greater min1 impedance and min1 stiffness at all levels tested. The min1 impedance ranged from 85-125 Ns/m for the females and from 57-85 Ns/m for the males; stiffness ranged from 21-42 kN/m (females) and 16-23 kN/m (males). The frequency corresponding to the min1 impedance was relatively constant (40-50 Hz) for both sexes. An analysis of variance showed that there were statistically significant min1 impedance and stiffness differences between the males and females at several levels.

7.COMPARISON OF MIN1 IMPEDANCE OF THE COMBINED THORACIC vs LUMBAR REGIONS FOR EACH SUBJECT



For most subjects the lumbar region exhibited a higher min1 impedance and stiffness when compared to the thoracic region. In the lumbar region the impedance values ranged from 88-150 Ns/m for the females (left portion of each figure) and 34-103 Ns/m for the males (right portion of each figure); and the stiffness ranged from 30-45 kN/m (females) and 10-30 kN/m (males). In the thoracic region the impedance ranged from 78-101 Ns/m (females) and 50-81 Ns/m (males); the stiffness ranged from 24-32 kN/m (females) and 14-28 kN/m (males). The frequency at which the impedance was minimum was nearly constant (40-50 Hz) in both regions. An analysis of variance showed that these regional differences were significant in four of the six female subjects.

DISCUSSION

An impulsive method for characterizing the *in vivo* dynamic mechanical behavior of the human spine was described and the results for 6 female and 5 male subjects were presented. A lower impedance value implies that the intervertebral joints are easier to excite and capable of larger motions and storage of larger amounts of energy[6]. The identification of the frequency of maximum mobility (natural frequency) of the thoraco lumbar spine is important, since lower forces can be used to excite a mechanical structure when applied at its natural frequency. In the 11 subjects examined we noted that the thoraco-lumbar spine exhibited a maximum mobility at about 40-50 Hz and was least mobile for frequencies centered around 70-90 Hz. Significant inter-subject and inter-sex variations in the dynamic impedance characteristics (peak1, min1, peak2) were noted along the spine.

FUTURE WORK

We are currently working on developing an analytical model to predict the PA mechanical behavior of the thoraco-lumbar spine which can be used by clinicians to (i) precisely quantify key dynamic characteristics of the spine (peak1, min1, peak2), (ii) identify spinal pathology, and (iii) assess the effectiveness of chiropractic manipulations in the treatment of LBP and other spinal disorders.

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