A Comparison of the Ortho*Imager*™ Static Lift Component and Hand Calculated Biomechanical Predictions of Forces on the L5/S1 Region of the Vertebral Column

Peter Sanzio, MSPT
Daniel Weber, MSPT
John Quatrone, MSPT

Background and Purpose. This study was a comparative analysis of the Static Lift component of the Ortho*Imager*™ and hand calculated biomechanical predictions of forces on the L5/S1 region of the vertebral column. **Subjects.** Two healthy males, ages 27 and 29, participated in this study. **Method.** Participants were videotaped in thirteen positions simulating static squat lifts. Still images were captured from video, and then analyzed utilizing the Ortho*Imager*™ static lift application. The resulting predictions were then hand-calculated, and compared to the Ortho*Imager*™ data. **Results.** The average percent difference for all variables ranged from 0.025 to 0.078. **Conclusion and Discussion.** The Ortho*Imager*™ does accurately utilize the calculations as compared to more traditional methods, with a small percent difference.

Introduction

Technology is steadily infiltrating all aspects of health care, as is the demand for objective and accurate documentation. This demand can be met with the use of software and imaging technology. These technologies must be valid in order to be useful.

One such application is the Ortho*Imager*™, a simplified two-dimensional biomechanical prediction software application. A component of the Ortho*Imager*™ is the static lift module, which is designed to analyze the angles of joints, and forces acting upon the L5/S1 junction.

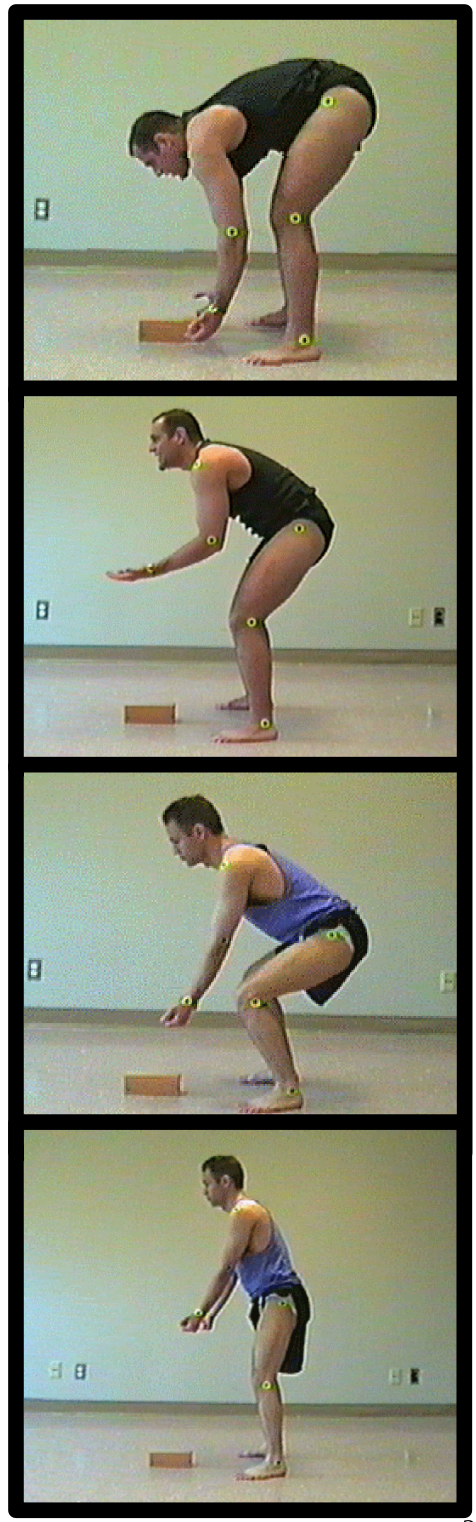
This study was a comparative analysis of the Static Lift component of the Ortho*Imager*™ and hand calculated biomechanical predictions of forces on the L5/S1 region of the vertebral column. This was undertaken in order to determine if this component of the Ortho*Imager*™ properly utilizes the biomechanical formulae contained in its algorithms.

Background

One of the primary sources for the biomechanical equations utilized by the Ortho*Imager*™ is Nordin and Frenkel, 1989. According to this source, body weight, muscle activity, and ligamentous stress produce the external loads upon the vertebral column.[1] These external loads are utilized to calculate the forces upon the spine during a lifting activity. Load bearing primarily takes place in the lumbar region.[1] Therefore the Ortho*Imager*™ focuses on this region, specifically the L5/S1 junction.

The position of the body will also effect the load upon the spine. As trunk flexion increases, the load upon the vertebral column increases due to an increase in forward moment.[1] Generally, external loads create the greatest force upon the vertebral column.[1] Lifting a heavy object, and carrying it over a distance may exert injurious forces upon the vertebral column.[1] Furthermore, the distance at which the object is held from the center of gravity of the person will effect force upon the vertebral column.[1] Carrying the object closer reduces the lever arm, decreasing the bending moment, thereby decreasing the force upon the spine.[1]

The Ortho*Imager*™ utilizes a simplified free body technique to calculate the static load upon the spine as an object is lifted. The three principle forces considered are the force produced by the upper body weight (UBW), the force produced by the object, and the force produced by the erector spinae muscle group. [1] These forces act at a distance from the center of motion of the vertebral column.[1] Moments are products of these forces and their perpendicular distance from the center of motion.[1] The weight of the object and UBW produce forward bending moments that are counterbalanced by the moment which is the product of the muscle force and its lever arm.[1] If an assumption is made that these forces are in equilibrium, the sum of the forces upon the spine can be predicted.[1]



Materials and methods

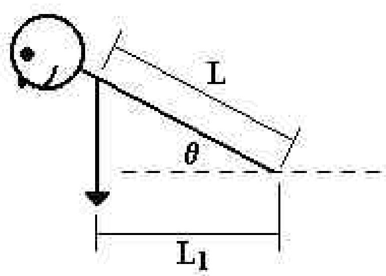
Two healthy males, ages 27 and 29, were the participants. The following bony landmarks were located via palpation, and highlighted with adhesive stickers: acromion process of the scapula, lateral epicondyle of the humerus, radial styloid, greater trochanter of the femur, lateral femoral condyle, and lateral malleolus of the fibula. They were asked to perform a series of positions simulating a squat lift, with no external load component. Load upon the vertebral column was due to internal force of body segment weights, position of the body segment, and forces produced by the erector spinae muscle group. The still images were digitized utilizing Capsnap™ - Video for Windows™, and then imported into the Ortho*Imager*™. The points highlighted by the adhesive stickers, as well as the ear canal and tip of the nose, were selected by using a mouse to manipulate a target-shaped cursor by the operator of the Ortho*Imager*™. The Ortho*Imager*™ calculated compressive forces, shearing forces, and torque at the L5/S1 junction of the vertebral column based upon algorithms using segment weights, anthropometric measurements, and angular joint values. The same calculations were performed longhand utilizing Nordin and Frenkel, 1989 formulae and a hand-held calculator. Figure 1-1 shows the calculations utilized. The Ortho*Imager*™ also utilizes these formulae. Also note that in the calculations performed by hand and those with the Ortho*Imager*™, the complement of trigonometric functions utilized by Nordin and Frenkel was employed. This is due to the fact that Nordin and Frenkel measure the angle of the trunk from a vertical reference line, whereas the Ortho*Imager*™ measures the trunk angle from a horizontal reference line. The two sets of calculations were compared using Excel™, and the percent difference was calculated.

Figure 1-1, Calculations

I. CALCULATION OF UPPER BODY WEIGHT (UBW) AND TRUNK LEVER ARM (L)

UBW= (0.63) (TOTAL BODY WEIGHT) = 0.63 (86.2 kg) = 54.306 kg
UBW= 54.306 kg (9.81N/ kg)= 532.742 N

θ



L= (0.16) (TOTAL HEIGHT)
L= (0.16) (170.18 cm) = 27.2288 cm
L≈ 0.2723 m
$\theta = 34^o$
L_1= cosine 34^o L = 0.2257 m

II. TORQUE (T)

TORQUE DUE TO UPPER BODY WEIGHT (T_{UBW})
T_{UBW} = (UBW)(L_1) = (532.742 N)(0.2257 m) = 120.2398 Nm

TORQUE DUE TO EXTERNAL LOAD CARRIED (T_{LOAD})
T_{LOAD}= (0 N)(L_1) = 0 N

TOTAL TORQUE (T_{TOTAL})
$T_{TOTAL} = T_{UBW} + T_{LOAD}$ = 120.2398 Nm

III. ERECTOR SPINAE FORCE (F_{ES})

F_{ES}= T_{TOTAL} / 0.05 m = 120.2398 Nm / 0.05 m = 2404.796 N

IV. COMPRESSION

COMPRESSION FROM EXTERNAL LOAD CARRIED (C_{LOAD})
C_{LOAD}= sin θ (0 N) = 0 N

COMPRESSION FROM UPPER BODY WEIGHT (C_{UBW})
C_{UBW}= sin θ (UBW) = (sin34^o)(532.742 N) = 297.91 N

COMPRESSION FROM ERECTOR SPINAE (C_{ES})
C_{ES}= cosine 8^o (F_{ES}) = cosine 8^o (2404.796 N) =2381.393 N

TOTAL COMPRESSION (C_{TOTAL})
$C_{TOTAL} = C_{UBW} + C_{LOAD} + C_{ES}$= 0 N + 297.91 N + 2381.393 N
C_{TOTAL}= 2679.3 N

V. SHEARING

SHEARING DUE TO EXTERNAL LOAD CARRIED (S_{LOAD})
S_{LOAD}= cosine θ (LOAD) = 0 N

SHEARING DUE TO UPPER BODY WEIGHT (S_{UBW})
S_{UBW}= cosine θ (UBW) = cosine 34^o (532.742 N) = 441.663 N

SHEARING DUE TO ERECTOR SPINAE (S_{ES})
S_{ES}= sin 8^o (F_{ES}) = sin 8^o (2404.796 N) =334.683 N

TOTAL SHEARING (S_{TOTAL})

$S_{TOTAL} = S_{LOAD} + S_{UBW} + S_{ES} = 0\text{ N} + 441.663\text{ N} + 334.683\text{ N}$

$S_{TOTAL} = 776.35\text{ N}$

VI. JOINT REACTION FORCE (J)

$$J = \sqrt{(Stotal)^2 + (Ctotal)^2}$$

$$J = \sqrt{(776.35N)^2 + (2679.3N)^2}$$

J = 2895.5N

Results:

Table 1 shows the differences for the following variables for each of the 13 trials:
total compression, total shearing, total torque (bending moment), total joint reaction force, erector spinae force (ESF), compression due to load, compression due to upper body weight (UBW), compression due to ESF, shearing due to load, shearing due to UBW, and shearing due to ESF.

The average percent difference for all variables ranged from 0.025 to 0.078. It was also noted that the only variable that the Ortho*Imager*™ did not calculate correctly was total joint reaction force. The developer was notified, and later informed the researchers that this was due to a keystroke error during programming involving the total compressive and total shearing forces when calculating total joint reaction forces. The developers have since corrected this error. The figures in the charts below for total joint reaction force reflect this correction.

Table 1: Comparative Trials

Ortho*Imager*™: those calculations determined by the OrthoImager™, biomechanical prediction software.
Manual: those calculations determined through "long-hand" procedures, or the manual use of calculating devices, paper and writing implements.
Biomechanical Calculations: biomechanical estimations determined for the L5/S1 region of the human spine.
Percent Difference: the statistical difference between like values. Equation = (((Part/Whole)-1)*100) or (((OrthoImager/Manual)-1)*100)
UBW: Upper Body Weight
ESF: Erector Spinae Force

Trial 1			
Biomechanical Calculations	**OrthoImager**	**Manual**	**Percent Difference**
Compression	2678.23	2679.3	-0.040
Shearing	775.98	776.22	-0.031
Torque (Bending Moment)	120.19	120.24	-0.042
Total Joint Reaction Force	2788.38	2789.47	-0.039
Erector Spinae Force	2403.88	2404.8	-0.038
Compression due to Load	0	0	0.000
Compression due to UBW	297.74	297.91	-0.057
Compression due to ESF	2380.49	2381.39	-0.038
Shearing due to Load	0	0	0.000
Shearing due to UBW	441.42	441.66	-0.054
Shearing due to ESF	334.56	334.56	0.000
Average Percent Difference			**-0.031**

Trial 2			
Biomechanical Calculations	**OrthoImager**	**Manual**	**Percent Difference**
Compression	2919.34	2920.53	-0.041
Shearing	915.54	915.99	-0.049
Torque (Bending Moment)	141.81	141.87	-0.042
Total Joint Reaction Force	3059.54	3060.81	-0.041
Erector Spinae Force	2836.24	2837.38	-0.040
Compression due to Load	0	0	0.000
Compression due to UBW	110.7	110.76	-0.054
Compression due to ESF	2808.63	2809.77	-0.041
Shearing due to Load	0	0	0.000
Shearing due to UBW	520.82	521.1	-0.054
Shearing due to ESF	394.73	394.89	-0.041
Average Percent Difference			**-0.037**

Trial 3			
Biomechanical Calculations	**OrthoImager**	**Manual**	**Percent Difference**
Compression	2911.36	2912.83	-0.050
Shearing	904.11	904.58	-0.052
Torque (Bending Moment)	140.04	140.11	-0.050
Total Joint Reaction Force	3048.51	3050.06	-0.051
Erector Spinae Force	2800.8	2802.22	-0.051
Compression due to Load	0	0	0.000
Compression due to UBW	137.81	137.88	-0.051
Compression due to ESF	2773.55	2774.95	-0.050
Shearing due to Load	0	0	0.000
Shearing due to UBW	514.31	514.59	-0.054
Shearing due to ESF	389.8	389.99	-0.049
Average Percent Difference			**-0.042**

Trial 4			
Biomechanical Calculations	**OrthoImager**	**Manual**	**Percent Difference**
Compression	2920.23	2921.96	-0.059
Shearing	918.8	919.32	-0.057
Torque (Bending Moment)	142.32	142.4	-0.056
Total Joint Reaction Force	3061.36	3063.17	-0.059
Erector Spinae Force	2846.33	2848.03	-0.060
Compression due to Load	0	0	0.000
Compression due to UBW	101.6	101.65	-0.049
Compression due to ESF	2818.63	2820.31	-0.060
Shearing due to Load	0	0	0.000
Shearing due to UBW	522.67	522.95	-0.054
Shearing due to ESF	396.13	396.37	-0.061
Average Percent Difference			**-0.046**

Trial 5			
Biomechanical Calculations	**OrthoImager**	**Manual**	**Percent Difference**
Compression	1737.3	1738.3	-0.058
Shearing	410.32	410.55	-0.056
Torque (Bending Moment)	63.56	63.59	-0.047
Total Joint Reaction Force	1785.10	1786.12	-0.057
Erector Spinae Force	1271.1	1271.85	-0.059
Compression due to Load	0	0	0.000
Compression due to UBW	478.56	478.83	-0.056
Compression due to ESF	1258.73	1259.47	-0.059
Shearing due to Load	0	0	0.000
Shearing due to UBW	233.41	233.54	-0.056
Shearing due to ESF	176.9	177.01	-0.062
Average Percent Difference			**-0.046**

Trial 6			
Biomechanical Calculations	**OrthoImager**	**Manual**	**Percent Difference**
Compression	2010.42	2011.58	-0.058
Shearing	509.78	510.07	-0.057
Torque (Bending Moment)	78.96	79.01	-0.063
Total Joint Reaction Force	2074.04	2075.24	-0.058
Erector Spinae Force	1579.24	1580.17	-0.059
Compression due to Load	0	0	0.000
Compression due to UBW	446.55	446.8	-0.056
Compression due to ESF	1563.87	1564.79	-0.059
Shearing due to Load	0	0	0.000
Shearing due to UBW	289.99	290.15	-0.055
Shearing due to ESF	219.79	219.92	-0.059
Average Percent Difference			**-0.048**

Trial 7			
Biomechanical Calculations	**OrthoImager**	**Manual**	**Percent Difference**
Compression	2901.54	2903.24	-0.059
Shearing	933.72	934.24	-0.056
Torque (Bending Moment)	144.63	144.71	-0.055
Total Joint Reaction Force	3048.08	3049.85	-0.058
Erector Spinae Force	2892.54	2894.25	-0.059
Compression due to Load	0	0	0.000
Compression due to UBW	37.14	37.16	-0.054
Compression due to ESF	2864.39	2866.08	-0.059
Shearing due to Load	0	0	0.000
Shearing due to UBW	531.16	531.44	-0.053
Shearing due to ESF	402.56	402.8	-0.060
Average Percent Difference			**-0.046**

Trial 8			
Biomechanical Calculations	**OrthoImager**	**Manual**	**Percent Difference**
Compression	1164.73	1165.39	-0.057
Shearing	210.55	210.67	-0.057
Torque (Bending Moment)	32.61	32.63	-0.061
Total Joint Reaction Force	1183.61	1184.28	-0.057
Erector Spinae Force	652.27	652.65	-0.058
Compression due to Load	0	0	0.000
Compression due to UBW	518.81	519.09	-0.054
Compression due to ESF	645.92	646.3	-0.059
Shearing due to Load	0	0	0.000
Shearing due to UBW	119.78	119.84	-0.050
Shearing due to ESF	90.78	90.83	-0.055
Average Percent Difference			**-0.046**

Trial 9			
Biomechanical Calculations	**OrthoImager**	**Manual**	**Percent Difference**
Compression	1837.16	1838.14	-0.053
Shearing	535.05	535.33	-0.052
Torque (Bending Moment)	81.45	81.49	-0.049
Total Joint Reaction Force	1913.49	1914.51	-0.053
Erector Spinae Force	1629	1629.86	-0.053
Compression due to Load	0	0	0.000
Compression due to UBW	224.02	224.14	-0.054
Compression due to ESF	1613.14	1613.99	-0.053
Shearing due to Load	0	0	0.000
Shearing due to UBW	308.34	308.5	-0.052
Shearing due to ESF	226.71	226.83	-0.053
Average Percent Difference			**-0.043**

Trial 10			
Biomechanical Calculations	**OrthoImager**	**Manual**	**Percent Difference**
Compression	978.64	978.92	-0.029
Shearing	204.37	204.45	-0.039
Torque (Bending Moment)	31.11	31.12	-0.032
Total Joint Reaction Force	999.75	1000.04	-0.030
Erector Spinae Force	622.22	622.32	-0.016
Compression due to Load	0	0	0.000
Compression due to UBW	362.47	362.66	-0.052
Compression due to ESF	616.17	616.26	-0.015
Shearing due to Load	0	0	0.000
Shearing due to UBW	117.77	117.84	-0.059
Shearing due to ESF	86.6	86.61	-0.012
Average Percent Difference			**-0.026**

Trial 11			
Biomechanical Calculations	**OrthoImager**	**Manual**	**Percent Difference**
Compression	450.48	450.95	-0.104
Shearing	23.08	23.1	-0.087
Torque (Bending Moment)	3.51	3.52	-0.284
Total Joint Reaction Force	451.07	451.54	-0.104
Erector Spinae Force	70.27	70.31	-0.057
Compression due to Load	0	0	0.000
Compression due to UBW	380.89	381.32	-0.113
Compression due to ESF	69.59	69.63	-0.057
Shearing due to Load	0	0	0.000
Shearing due to UBW	13.3	13.31	-0.075
Shearing due to ESF	9.78	9.78	0.000
Average Percent Difference			**-0.079**

Trial 12			
Biomechanical Calculations	**OrthoImager**	**Manual**	**Percent Difference**
Compression	1188.1	1188.72	-0.052
Shearing	279.5	279.64	-0.050
Torque (Bending Moment)	42.55	42.57	-0.047
Total Joint Reaction Force	1220.53	1221.17	-0.052
Erector Spinae Force	850.96	851.41	-0.053
Compression due to Load	0	0	0.000
Compression due to UBW	345.42	345.6	-0.052
Compression due to ESF	842.68	843.12	-0.052
Shearing due to Load	0	0	0.000
Shearing due to UBW	161.07	161.15	-0.050
Shearing due to ESF	118.43	118.49	-0.051
Average Percent Difference			**-0.042**

Trial 13			
Biomechanical Calculations	**OrthoImager**	**Manual**	**Percent Difference**
Compression	1821.81	1822.77	-0.053
Shearing	528.18	528.46	-0.053
Torque (Bending Moment)	80.4	80.45	-0.062
Total Joint Reaction Force	1896.83	1897.83	-0.053
Erector Spinae Force	1608.09	1608.94	-0.053
Compression due to Load	0	0	0.000
Compression due to UBW	229.37	229.49	-0.052
Compression due to ESF	1592.44	1593.28	-0.053
Shearing due to Load	0	0	0.000
Shearing due to UBW	304.38	304.54	-0.053
Shearing due to ESF	223.8	223.92	-0.054
Average Percent Difference			**-0.044**

Discussion:
The small percent difference indicates that the Ortho*Imager*™ does accurately utilize the calculations as compared to more traditional methods. The small differences found may be contributed to differences in the rounding of numbers and/or the use of significant figures. The researchers did not round figures until after all the calculations were made. The Ortho*Imager*™, however, rounds numbers to two decimal places throughout the calculation processes.

Conclusion:
The Ortho*Imager*™ correctly utilizes the biomechanical prediction formulae contained within its programming. With the Ortho*Imager*™, the practitioner will be able to utilize these commonly accepted formulae more easily. Therefore the researchers contend that the Ortho*Imager*™ is an excellent laborsaving tool for researchers and clinicians that would formerly need to perform these calculations by hand.

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About the authors:
The authors are master degree graduates of the Physical Therapy Program at the College of Staten Island, City University of New York. Each has previous experience in biomechanical research studies including a recent, yet unpublished work entitled “The Effect of Wearing A Lumbar Support Belt Upon the Degree of Trunk Inclination and The Compression and Shearing Forces at the L5/S1 Junction of A Young Adult Performing A Maximal Static Squat Lift”. Planned future studies include the investigation of the biomechanical and kinesiological effects of the human form within a neutrally buoyant environment and exploring feasible countermeasures to battle space atrophy as a result of living in microgravity.

Peter Sanzio, MSPT: jdp_ent@hotmail.com
Daniel Weber, MSPT: danweber@erols.com
John Quatrone, MSPT

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Donald Helt III: donhelt@yahoo.com

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